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LIST OF ABBREVIATIONS AND ACRONYMS

Δ	Change
Ψ	Probability of Occurrence
$\bar{x}$	Mean
w_i	Akaike Weight
AIC	Akaike's Information Criteria
AIC_c	Akaike's Information Criteria adjusted for small sample sizes
ANOVA	Analysis of Variance
BCVI	Black-capped Vireo (*Vireo atricapilla*)
BLM	United States Department of Interior's Bureau of Land Management
C	Celsius
CAP	Canonical Analysis of Principal Coordinates
CI	95% Confidence Interval
CDS	Conventional Distance Sampling
CV	Coefficient of Variation
df	Degrees of Freedom
ESD	Ecological Site Descriptions
ESRI	Environmental Systems Research Institute
F	Test Statistic for Analysis of Variance
FS	United States Department of Agriculture's Forest Service
GCWA	Golden-cheeked Warbler (*Setophaga chrysoparia*)
ha	Hectares
K	Number of Parameters
km	Kilometers
km/h	Kilometers per Hour
m	Meters
MD	Moderate Disturbance
min	Minute
MLRA	Major Land Resource Area
mm	Millimeters
n	Sample Size
ND	No Disturbance
NRCS	United States Department of Agriculture'sNatural Resource Conservation Service
P	Probability Value
p	Parameter
r	Pearson's Correlation Coefficient
RDA	Redundancy Analysis
SD	Severe Disturbance
STM	State-and-Transition Model
t	Test Statistic for t-test
TPWD	Texas Parks and Wildlife Department
USDA	United States Department of Agriculture
USFWS	United States Fish and Wildlife Service
USGS	United States Geological Survey
VIF	Variance Inflation Factor

KEYWORDS

black-capped vireo, ecological site description, ecosite, endangered species, golden-cheeked warbler, prescribed burning, *Setophaga chrysoparia*, state-and-transition model, *Vireo atricapilla*, wildfire

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ABSTRACT

In recent years, federal land management agencies have collaborated to standardize assessments of rangeland health. These assessments incorporate state-and-transition concepts of ecosystem function using ecological site descriptions (ESDs) initially developed to provide information on the soil, topography, climate, and vegetation of an area. Combined, ESDs and state-and-transition models (STMs) describe existing and potential plant community dynamics. Unlike previous methods used to assess rangeland health, STMs take into account that multiple stable states may exist in space and time across sites, and that reversible and directional changes in vegetation can occur in response to factors such as fire, erosion, weather, and management activities. Wildlife responses are seldom incorporated into this framework. However, combining STMs, ESDs, and species-specific demographic information has great potential to provide land managers with tools that classify current ecosystem conditions, predict vegetative change in space and time, and inform management for maintaining or improving key habitat features for species of interest. We used an STM framework to predict multiple habitat-specific demographic responses of two federally endangered bird species to fire-induced changes in vegetative communities within four geographically-separated study areas in Oklahoma and Texas. Our study species, the federally endangered golden-cheeked warbler (*Setophaga chrysoparia*; hereafter warbler) and the federally endangered black-capped vireo (*Vireo atricapilla*; hereafter vireo), represent avifauna with overlapping breeding distributions, and though the two species co-occur in some locations, they typically utilize vegetation in different portions of the successional spectrum. We used Canonical Analysis of Principal Coordinates to identify the total amount of variance in our vegetation datasets explained by ecological site and to test site-, territory-, and nest-scale null hypotheses that topographical features, vegetation structure, and vegetation composition were similar across ecological sites within each study area. Ecological site explained little variation (<12%) in our datasets and we were able to link warbler and vireo demographic information to a single STM for each study area, suggesting that STMs intended to assist with wildlife management may be most effectively developed at the level of multiple ecological sites or landscapes. As expected given the known natural history of the warbler and vireo, our multi-species, multi-response STMs showed that there is a general trend of increasing probability of warbler occupancy and nesting success as succession proceeds post-burn and a general trends of decreasing probability of vireo occupancy and nesting success as succession proceeds post-burn. However, the exact timing and magnitude of differences across vegetative states may depend on site-specific factors including prey availability, predator abundance, and predator assemblage, which are also mediated by disturbance. Further development and testing of STMs that include predictions for concurrent wildlife responses could allow land managers to visualize trade-offs in occupancy and reproductive success as succession proceeds and assist with determining the types, levels, intensities, and locations of management activities that will minimize the negative effects or enhance the positive effects of disturbance on wildlife.

OBJECTIVES

We used previously collected data and expert opinion to hypothesize how the types, levels, intensities, and locations of fire disturbance could create habitat conditions outlined in region-specific, conceptualized state-and-transition models (STMs) for two endangered bird species, the golden-cheeked warbler (*Setophaga chrysoparia*; hereafter warbler) and the black-capped vireo (*Vireo atricapilla*; hereafter vireo). We then collected data to quantify habitat-specific warbler and vireo demographic responses to vegetation conditions across ecological sites per study area and we conducted analyses to identify thresholds at which avian responses changed as a function of vegetation structure and composition. We used an extensive vegetation data set to quantify region-specific, vegetation-based STMs in relation to time since burn. Finally, we linked warbler and vireo demographic information to models that depict plant community transformations in each of our study areas. Through this process, we demonstrate a multi-species, multi-response STM approach that could allow land managers to determine the types, levels, intensities, and locations of management activities to minimize the negative effects or enhance the positive effects of disturbance on wildlife.

BACKGROUND

In recent years, federal land management agencies, such as the United States Department of Agriculture's Forest Service (FS) and Natural Resource Conservation Service (NRCS) and the United States Department of the Interior's Bureau of Land Management (BLM), have collaborated to standardize assessments of rangeland health (i.e., the degree to which the integrity of soil and ecological processes of rangeland ecosystems are maintained; USDA 1997, Pellant et al. 2005). These assessments incorporate state-and-transition concepts of ecosystem function using ecological site descriptions (ESDs) initially developed to provide information on the soil, topography, climate, and vegetation of an area (Pellant et al. 2005). Combined, ESDs and state-and-transition models (STMs) describe existing and potential plant community dynamics (Fig. 1; Bestelmeyer et al. 2003, 2009; Briske et al. 2008). Unlike previous methods used to assess rangeland health, STMs take into account that multiple stable states may exist in space and time across sites, and that reversible and directional changes in vegetation (i.e., successional phases) can occur in response to factors such as fire, erosion, weather, and management activities (Westoby et al. 1989, Briske et al. 2005). Wildlife responses are seldom incorporated into this framework. However, combining ESDs, STMs, and species-specific demographic information has great potential to provide land managers with powerful tools that classify current ecosystem conditions, predict vegetative change in space and time, and inform management for maintaining or improving key habitat features for species of interest.

Ecological thresholds, defined as points or zones where a rapid change occurs from one ecological state to another as a result of a change in one or more key factors (Groffman et al. 2006), were not referenced in the original STM framework (Westoby et al. 1989), but have since become a focal point in the development and application of STMs (e.g., Stringham et al. 2003). From a vegetation perspective, a threshold represents the limits of a vegetative state's resilience (Briske et al. 2008); once a threshold is crossed, transformation between states occurs, and the new state may include a plant community with different structure, composition, and function from the original state (Westoby et al. 1989, Laycock 1991, Bestelmeyer 2006). STMs represent observed or theoretical vegetative states and successional changes as simple box-and-arrow diagrams (Fig. 1). However, actual vegetative thresholds can be difficult to identify and interpret because they often represent complex interacting components (Briske et al. 2005). Understanding the nature of such relationships in response to both natural and anthropogenic disturbance is necessary for development of more effective STMs.

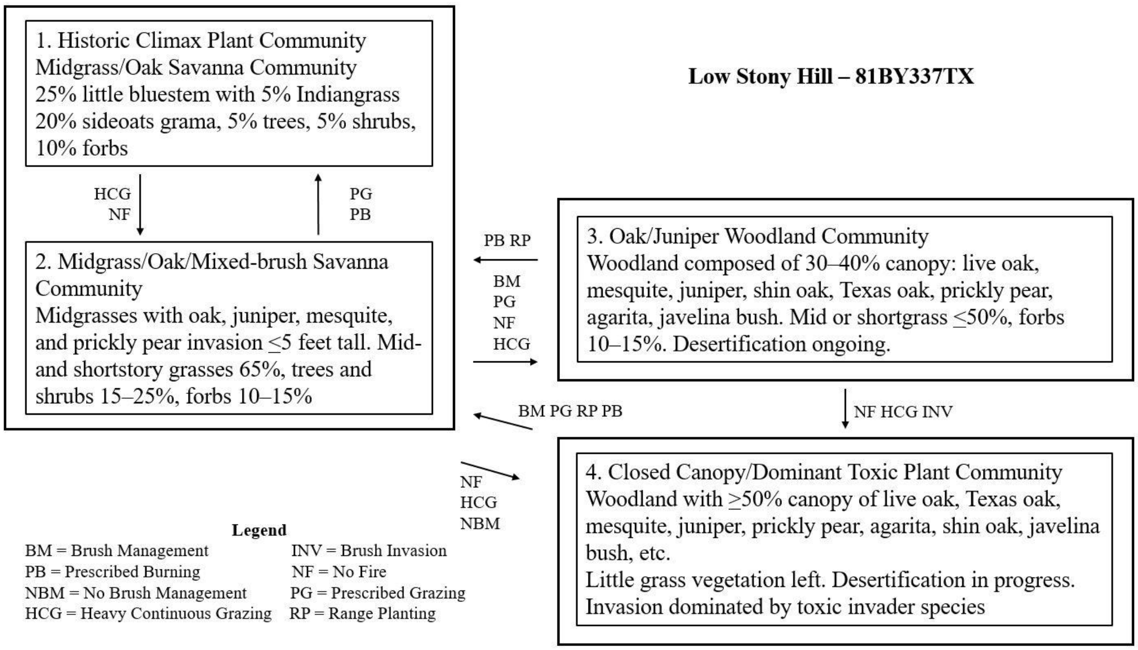

Figure 1. Example state-and-transition model for ecological site Low Stony Hill (81BY337TX) in Major Land Resource Area 81C–Edwards Plateau, Eastern Part as depicted by the United States Department of Agriculture's Forest Service Natural Resource Conservation Service's Ecological Site Description System for Rangeland and Forestland portal (https://esis.sc.egov.usda.gov). Each box represents one phase or seral stage of vegetation development. Transitions between states are represented by arrows.

Spatial and temporal variation in plant community structure and composition can drive concurrent ecological thresholds in wildlife responses, which can also be difficult to identify. However, Hemstrom et al. (2002) demonstrated that STMs can be used to evaluate the potential effects of restoration activities on the spatial distribution of greater sage-grouse (*Centrocercus urophasianus*) habitat in the western United States. Their analyses included identification of ecological thresholds necessary to cross before vegetation could be returned to potential sage grouse habitat after successional transitions occurred on the landscape. Later, to evaluate the utility of STMs for understanding and predicting potential changes in habitat use by wildlife, Holmes and Miller (2010) compared the abundance of grasshopper sparrows (*Ammodramus savannarum*) across five community phases (i.e., distinctive plant communities and associated dynamic soil property levels that can occur over time within a state; Bestelmeyer et al. 2009) that represented two states (i.e., a suite of temporally-related plant communities and associated dynamic soil properties that produce persistent, characteristics structure and functional ecosystem attributes; Bestelmeyer et al. 2009) in the Columbia Basin, Oregon. Holmes and Miller (2010) determined that their STM was a powerful predictor of relative grasshopper sparrow abundance and provided insight into how bird abundance could change in response to different disturbance agents or restoration efforts. The authors suggested that future studies concurrently evaluate multiple demographic parameters using the STM framework.

According to Burcsu et al. (2014) and others, the simple structure of STMs is a major strength of the modeling approach. In addition, the results are well suited for both communication of results to non-technical audiences and to stakeholders with a deep ecological understanding, and the models provide for useful interpretation of available knowledge at a defined scale of analyses for decision-making (Burcsu et al. 2014). STMs also represent testable hypotheses, provide opportunities for data-driven adaptive management, and could lead to improved landscape-scale conservation planning. However, wildlife biologists have been slow to further test or adopt STMs. This is, in part, because the utilization of such models requires extensive data regarding vegetation responses to disturbance and habitat requirements of target species. Analyses are further complicated for co-occurring species with contrasting habitat requirements.

To address some of these overarching challenges, we used an STM framework to predict multiple habitat-specific demographic responses (e.g., density, nest success) of two bird species to disturbance-induced changes in vegetative communities within four geographically separated study areas. Our study species, the federally endangered golden-cheeked warbler (*Setophaga chrysoparia*; hereafter warbler) and the federally endangered black-capped vireo (*Vireo atricapilla*; vireo hereafter), represent avifauna with overlapping breeding distributions, and though the two species co-occur in some locations, they typically utilize vegetation in different portions of the successional spectrum (Grzybowski 1995, Ladd and Gass 1999). Given their conservation status, there are relatively more data pertaining to the distribution, abundance, and behavior of these species compared to other taxa, providing a robust foundation for developing and testing a multi-species, multi-response STM framework.

Many factors can influence vegetation dynamics in warbler and vireo habitat (e.g., historic conditions, grazing management, mechanical brush control, temperature and precipitation). However, we focused on prescribed burning and wildfire as the mechanistic drivers of vegetation dynamics for our STMs. This is because warblers and vireos both occupy habitat influenced by fire and because fire represents a tool that land managers can implement to assist with conservation measures for these two species (Wilkins et al. 2006, Groce et al. 2010). Our broader goal was to demonstrate a multi-species, multi-response STM approach that could allow land managers to determine the types, levels, intensities, and locations of management activities to minimize the negative effects or enhance the positive effects of disturbance on wildlife.

STUDY SPECIES

The warbler is a Neotropical migratory songbird that breeds from March–June in mature oak-juniper (*Quercus*-*Juniperus*) woodlands in central Texas (Fig. 2) and winters in pine-oak (*Pinus*-*Quercus*) forests in the highlands of Chiapas (Mexico), Guatemala, Honduras, El Salvador, and Nicaragua (Ladd and Gass 1999, Groce et al. 2010). The United States Fish and Wildlife Service (USFWS) listed the warbler as endangered in 1990, citing habitat loss and fragmentation as the primary threats to warbler persistence (USFWS 1990). The vireo is a Neotropical migratory songbird that breeds from April–July in early successional, shrub-scrub vegetation in Oklahoma and Texas in the United States (Fig. 2) and in Coahuila, Nuevo León, and Tamaulipas in Mexico (Benson and Benson 1990, Grzybowski 1995, Wilkins et al. 2006, González et al. 2014). The vireo's wintering habitat extends from Sinaloa to Oaxaca along the Pacific coast of Mexico and consists of tropical dry forests and pine-oak forests (Grzybowski 1995, Wilkins et al. 2006, Colón et al. 2015). The USFWS listed the vireo as endangered in 1987, citing habitat loss and brood parasitism by brown-headed cowbirds (*Molothrus ater*; hereafter cowbird) as the primary drivers of vireo population decline (USFWS 1987).

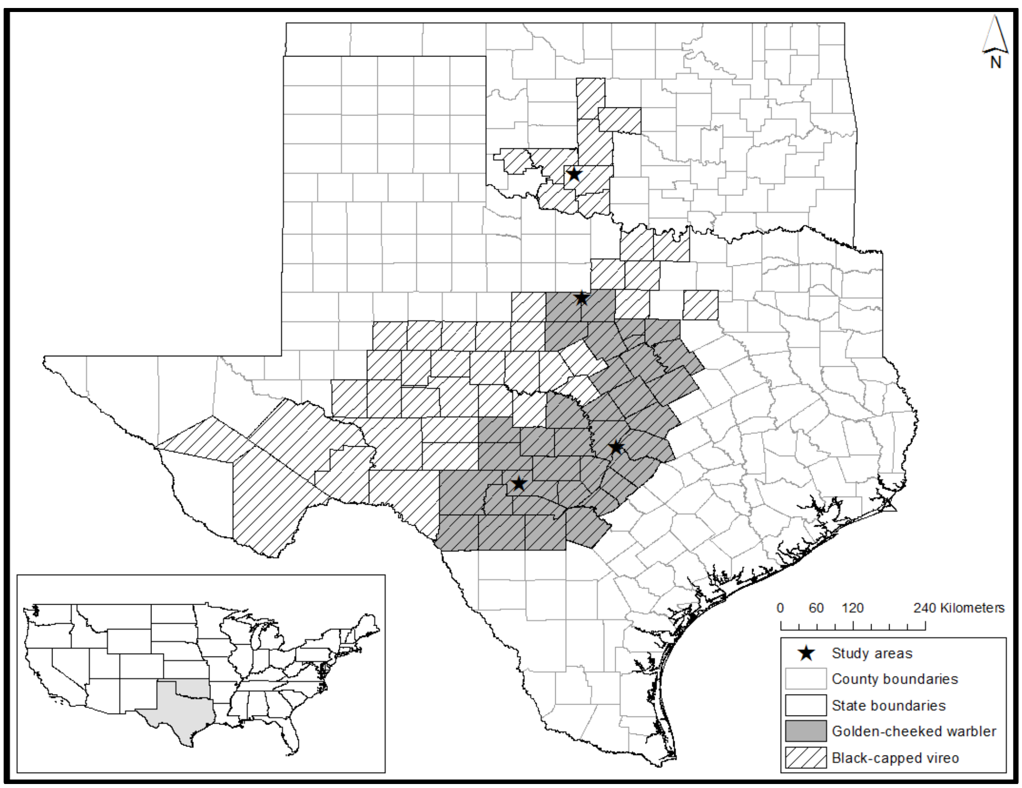

Figure 2. Golden-cheeked warbler (*Setophaga chrysoparia*) and black-capped vireo (*Vireo atricapilla*) breeding ranges in the United States and the general locations of study areas we used to examine the compatibility of fire with management of these two endangered songbirds. Study areas north to south included (1) Wichita Mountains Wildlife Refuge and adjacent Fort Sill Military Reservation in Oklahoma, (2) Possum Kingdom State Park in Texas, (3) Balcones Canyonlands National Wildlife Refuge and nearby private lands in Texas, and (4) Kerr Wildlife Management Area in Texas.

Similar to other threatened and endangered species (e.g., Kirtland's warbler [*S. kirtlandii*] and red-cockaded woodpecker [*Picoides borealis*]; Hunter et al. 2001), warblers and vireos occupy habitat that is influenced by disturbance, including wildfire and prescribed burning (Grzybowski 1995, Ladd and Gass 1999). Prior to European settlement, fire mediated vegetative community dynamics in warbler breeding habitat (Smeins 1980, Fonteyn et al. 1988, Diamond et al. 1995, Diamond 1997). As such, low-intensity surface fires likely had a negligible effect on the abundance and productivity of this species. However, long-term fire suppression and drought conditions have altered the vegetative dynamics in mature oak-juniper forests (Fuhlendorf et al. 1996). Therefore, unrestricted wildfire is of concern in warbler breeding habitat (Reemts and Hansen 2008). During a recent study, which represents the only known research examining the short-term, immediate effects of prescribed fire on fuels, vegetation, and warbler demographics in oak-juniper woodlands, Reidy et al. (2016) found that warbler density, but not productivity, was lower on treated plots.

Although vireos will occupy and successfully breed in mature oak-juniper woodland (Pope et al. 2013), vireos typically occur in early-successional vegetation maintained by climatic conditions, edaphic features, and periodic disturbance (e.g., wildfire, prescribed burning, mechanical removal of vegetation) (Grzybowski 1995). Previous research in Texas (Tazik and Cornelius 1993, Cimprich 2002, Dufault 2004) and Oklahoma (Grzybowski 1989, 1990) suggests that vireos move into sites with recent fire histories, though the exact timing and circumstances of recolonization are unknown. Because warbler and vireo habitats may overlap and are adjacent in some portions of the species' breeding ranges, the use of prescribed burning as a management tool may be limited in close proximity to mature oak-juniper woodland. Reemts and Cimprich (2014) found that mechanical mastication of vegetation provides an effective substitute for the use of prescribed fire to create or maintain vireo habitat in central Texas. However, further study is needed to determine if this method is appropriate elsewhere.

APPROACH

Outbreaks of significant wildfires in Texas and Oklahoma in 2010 and 2011 (e.g., TPWD 2011), coupled with various prescribed burning regimes on public and private lands occupied by warblers and vireos, provided us with a unique opportunity to assess habitat-specific demographic responses of warblers and vireos to a wide range of fire effects, including the most severe of such disturbances. We first used previously collected data and expert opinion to hypothesize how the types, levels, intensities, and locations of fire disturbance could create the warbler and vireo habitat conditions outlined in a conceptualized STM (Fig. 3). We then selected four geographically separated study areas that represented different vegetative communities with various fire histories (Fig. 2). Our four study areas included two study areas in Texas occupied by warblers and vireos, one study area in Texas occupied by warblers only, and one study area in Oklahoma occupied by vireos only. Within each study area, we collected data to quantify habitat-specific warbler and vireo demographic responses to vegetation, including avian metrics associated with occupancy, abundance, and reproduction, and we conducted analyses to identify thresholds at which avian responses changed as a function of vegetation structure and composition. We then used an extensive vegetation data set to quantify region-specific, vegetation-based STMs in relation to time since burn. Finally, we linked warbler and vireo demographic information to models that depict plant community transformations in each region. As described above, our broader goal was to demonstrate a multi-species, multi-response STM approach that could allow land managers to determine the types, levels, intensities, and locations of management activities to minimize the negative effects or enhance the positive effects of disturbance on wildlife. We conducted all spatial mapping using ArcGIS v. 10.3 (ESRI 2014), bird density analyses using Program DISTANCE v. 7.1 (Thomas et al. 2010), and all statistical tests using R v. 3.4.1 (R Development Core Team 2017).

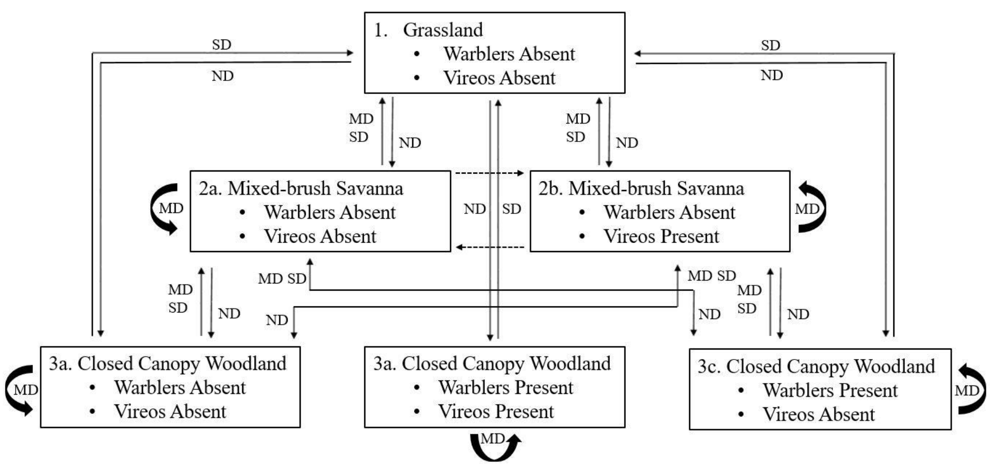

Figure 3. A box-and-arrow diagram representing hypotheses for endangered golden-cheeked warbler (*Setophaga chrysoparia*) and endangered black-capped vireo (*Vireo atricapilla*) occupancy in relation to prescribed burning or wildfire in central Texas and southwestern Oklahoma. “ND”, “MD”, and “SD” are defined as “No Disturbance”, “Moderate Disturbance”, and “Severe Disturbance”. Factors unrelated to fire can influence occupancy for some species (e.g., conspecific attraction; Farrell et al. 2012). We included one pair of dashed arrows between 2a and 2b to acknowledge an instance where this could occur.

METHODS

Study Area

Our study region included the western edge of the Cross Timbers in Oklahoma, the northern and eastern portions of the Edwards Plateau in Texas, and the eastern edge of the Rolling Plains in Texas. The western edge of the Cross Timbers in Oklahoma includes the Wichita Mountains, an igneous mountain range with elevations ranging between 420–730 m (Stambaugh et. al. 2009). This region in the southern plains of the United States is a transition zone between oak forest communities and mixed-grass prairie (Küchler 1964) that supports breeding habitat for vireos. The Edwards Plateau in Texas is characterized by steep canyons with broad plateaus of limestone bedrock (Sellards 1933) with elevation ranging from ~30 m to >900 m. Historically dominated by savanna grasslands, the Edwards Plateau now represents a mixture of oak savanna, shrubland, and mature oak-juniper (*Quercus-Juniperus*) woodland that supports breeding habitat for both warblers and vireos. The Rolling Plains in Texas was once composed of tall and mid-grass prairie, but as a result of heavy grazing and fire suppression, is now dominated by mesquite-encroached shortgrass savanna (Archer et al. 1995). Stream floodplains in this region are dominated by various hardwood species, and Ashe juniper (*J. ashei*) is common on steep slopes along rivers.

Our study areas, which represented a range of ecological conditions and fire histories, were (1) Wichita Mountains Wildlife Refuge and adjacent Fort Sill Military Reservation (collectively referred to as Wichita Mountains) in Oklahoma, (2) Possum Kingdom State Park (hereafter Possum Kingdom) in Texas, (3) Balcones Canyonlands National Wildlife Refuge and nearby private lands (collectively referred to as Balcones) in Texas, and (4) Kerr Wildlife Management Area (hereafter Kerr) in Texas (Fig. 2). Our study areas were located within four Major Land Resource Areas (MLRAs), which are geographically associated land resource units that have value in interstate, regional, and national planning (USDA 2006). The NRCS's Agriculture Handbook 296 identifies each MLRA with a descriptive geographic name and provides information on the physiography, geology, climate, water, soils, biological resources, and typical land use practices in the region (USDA2006). Below, we detail the pertinent characteristics of each MLRA represented in our study areas as presented in Handbook 296. We also describe the characteristics of our study areas, which we selected based on the known breeding locations of warblers and vireos, wildfire history, prescribed burn frequency, and representation of ecological sites.

Wichita Mountains

The Wichita Mountains study area was located within the 82B–Wichita Mountains Major Land Resource Area (MLRA) in southwestern Oklahoma and included eight, 23–108 ha study sites at the Wichita Mountains Wildlife Refuge (34°44' N, -38°44' W) and adjacent Fort Sill Military Reservation (34°42' N, -98°31' W) (Fig. 2). The landscape of the Wichita Mountains MLRA is characterized by rugged granite hills and mountains. Average annual precipitation is 660–785 mm, with most rainfall occurring in spring and fall. Average annual temperature is 15–17°C. The freeze-free period averages 230 days and ranges from 220–245 days. Soils in the Wichita Mountains MLRA support mid and tall prairie grasses, including big bluestem (*Andropogon gerardii*), blue grama (*Bouteloua gracilis*), and buffalograss (*B. dactyloides*), interspersed with trees. Farms and ranches make up nearly all of the private land in this MLRA. Livestock grazing is the dominant land use, and most of the rangeland is used for cow-calf operations. The historic fire frequency in the Wichita Mountains MLRA is variable and has decreased since European settlement (Stambaugh et. al 2009). Each year from 1938–2005, ~880 ha burned from wildfires and prescribed fires resulting in a 27-year fire rotation period (R. Wood, U.S. Fish and Wildlife Service, unpublished data). Scrubland vegetation inhabited by vireos in this region includes blackjack oak (*Q. marilandica*), post oak (*Q. stellata*), eastern red cedar (*J. virginiana*), and other deciduous woody species (Grzybowski et al. 1994). Management activities at the Refuge and Fort Sill include cowbird trapping, prescribed burning, and grazing.

Possum Kingdom

The Possum Kingdom study area was located within the 80B–Texas North-Central Prairies Major Land Resource Area (MLRA) in north central Texas and included one 700 ha study site at Possum Kingdom State Park (32°52N, -98°34W) (Fig. 2). The Texas North-Central Prairies MLRA is primarily an eroded plateau underlain by limestone and shale. Average annual precipitation is 660–840 mm, with most rainfall occurring as high-intensity, convective thunderstorms during spring and fall. Average annual temperature is 17–19°C. The freeze-free period averages 260 days and ranges from 245–270 days. Soils in the Texas North-Central Prairies MLRA support oak savanna vegetation with an understory of tall grasses, including little bluestem (*Schizachyrium scoparium*), Indiangrass (*Sorghastrum nutans*), and switchgrass (*Panicum virgatum*), interspersed with trees. Farms and ranches make up nearly all of the private land in this MLRA. Most of the rangeland and pasture is grazed by beef cattle, with a small acreage grazed by sheep and goats. Many ranches in this region are also managed for wildlife, including white-tailed deer (*Odocoileus virginianus*), dove (*Zenaida* spp.), and northern bobwhite (*Colinus virginianus*). Wildfires historically occurred at 4–12 year intervals in this region (Frost 1998), which would have favored grasses over woody plants. However, over the last 50 years, the spatial extent of mature oak-juniper woodland has increased in the Texas North-Central Prairie. In 2011, a grouping of four wildfires occurred in the region and consumed ~600 km^2 of vegetation in Stephens, Young, and Palo Pinto counties. Vegetation inhabited by warblers at Possum Kingdom includes post oak, blackjack oak, and cedar elm (*Ulmus crassifolia*). Honey mesquite (*Prosopis glandulosa*), gum bumelia (*Sideroxylon lanuginosum*), skunkbush sumac (*Rhus trilobata*), and Ashe juniper are also common within the study area (TPWD 2014). Warblers inhabited remaining mature oak-juniper woodland at Possum Kingdom for the duration of our study. We did not detect vireos at Possum Kingdom prior to the year that the current study began, but we did detect a small number of vireos at the site following the 2011 wildfires, which burned ~70% (500 ha) of oak-juniper woodland at the State Park (Long et al. 2015).

Balcones

The Balcones study area was located within the 81C–Edwards Plateau, Eastern Part Major Land Resource Area (MLRA) in central Texas and included 21, 30–486 ha study sites at the ~8,100 ha Balcones Canyonlands National Wildlife Refuge (30°39' N, -98°02' W) and nearby private properties (Fig. 2). The Edwards Plateau, Eastern Part MLRA consists of limestone ridges, canyons, and gently sloping valley floors. Average annual precipitation is 610–760 mm, with most rainfall occurring during spring and fall. Average annual temperature is 17–20°C. The freeze-free period averages 275 days and ranges from 235–310 days, lengthening to the south. Soils in the Edwards Plateau, Eastern Part MLRA support a plant community of mid or tall grasses (e.g., little bluestem, Texas grama [*B. rigidiseta*]), shrubs (e.g., escarpment cherry [*Prunus serotina*], elbowbush [*Forestiera pubescens*]), and trees (e.g., live oak [*Q. fusiformis*], Texas oak [*Q. buckleyi*], post oak, Ashe juniper). Most of this area is used for grazing and wildlife. Wildfires occurred at frequent intervals in this region (Frost 1998) maintaining the spatial distribution of woody species. Warblers and vireos both occur at Balcones. Common management activities on the Refuge and surrounding private lands include cattle grazing, prescribed burning, mechanical treatments (i.e., flat cut, dozer, masticator, and shaded fuel break), deer management, feral hog trapping, and cowbird control. Based on USFWS records, portions of the Refuge study sites that we surveyed were last burned between 2009 and 2014. Our study sites on private properties in this MLRA had no known history of fires.

Kerr

The Kerr study area was located in the 81B–Edwards Plateau, Central Part Major Land Resource Area in south-central Texas and included 11, 27–164 ha study sites at the ~2,600 ha Kerr Wildlife Management Area (30°05' N, -99°30' W). The Edwards Plateau, Central Part MLRA consists of plateaus and limestone hills incised by deep canyons and gently sloping valley floors. Average annual precipitation is 485–815 mm, with most rainfall occurring during spring and fall. Average annual temperature is 17–20°C. The freeze-free period averages 250 days and ranges from 230–270 days. Soils in the Edwards Plateau, Central Part MLRA support a plant community of mid or tall grasses (e.g., little bluestem, Texas wintergrass [*Nassella leucotricha*]), shrubs (e.g., flameleaf sumac [*R. lanceolata*], Mexican persimmon [*Diospyros texana*]), and trees (e.g.,live oak, Texas oak, black-jack oak, Ashe juniper). Most of this area is used for grazing and wildlife. Wildfires have occurred at 13–25 year intervals in this region (Frost 1998). Woody plant control has likely varied in accordance with the intensity and severity of fires. Warblers and vireos both occur at the Kerr. Land management includes cattle grazing, feral hog trapping, cowbird control, prescribed burning at variable frequencies, thinning, and mulching. According to state records, the Management Area study sites that we surveyed were last burned between 1999 and 2012.

State-and-Transition Model Development

Peterson (1984) suggested that state-and-transition models (STMs) focus on the alternative states and dynamics of an environmentally uniform area. As described above, NRCS's range assessments integrate STM concepts and Ecological Site Descriptions (ESDs; also referred to as ecosites), which are assumed to have similar vegetative communities and responses to disturbance based on recurring soil, landform, geological, and climate characteristics (Pellant 2005). However, vegetative differences among ecosites per Major Land Resource Area (MLRA) are rarely quantified and the number of ecological sites per MLRA can be extensive, resulting in a large number of possible STMs per MLRA. As such, Bestelmeyer (2015) suggested that STMs might be most effectively developed at the level of multiple ecological sites or landscapes.

Prior to data collection, we obtained MLRA-specific STMs for all ecological sites that occurred within our study areas from NRCS's ESD System for Rangeland and Forestland reports portal (https://esis.sc.egov.usda.gov). When there was more than one ESD with the same primary site name within the MLRA, we selected one ESD and STM diagram to represent each ecological site. For example, Kerr occurs within the 081B-Edwards Plateau, Central Part MLRA. Within this MLRA there are two ESDs for Clay Loam: 'Clay Loam 19–23" PZ' with Site ID R081BY325TX and 'Clay Loam 23–31" PZ' with Site ID R081BY326TX. Based on their primary field names (i.e., Clay Loam), these two ecosites should share soil characteristics, but based on their secondary field names (i.e., 19–23" PZ and 23–31" PZ), these two ecosites should represent areas with different climate features. However, in their current state of development, the climate profiles, ecological dynamics, plant communities, and resulting STMs are functionally similar for both ecosites. As such, we used the most detailed Clay Loam ESD report to this represent this ecosite category within the 081B-Edwards Plateau, Central Part MLRA.

After we identified the representative ecosite categories for each MLRA, we extracted the slope, aspect, and elevation for each vegetation survey point using Digital Elevation Models acquired from the National Elevation Dataset (https://lta.cr.usgs.gov/NED) (see below for vegetation survey methodology). We then used Canonical Analysis of Principal Coordinates (CAP; Legendre and Anderson 1999, Anderson and Willis 2003) to identify the total amount of variance in our datasets explained by ecosite and to test site-, territory-, and nest-scale null hypotheses that topographical features, vegetation structure, and vegetation composition were similar across ecosites within each study area (see below for detailed description of the vegetation survey methods we used at each spatial scale). CAP differs from traditional redundancy analyses (RDA) because any distance measure can be used, and it accounts for correlation structures among variables in the data set (Legendre and Anderson 1999, Anderson and Willis 2003).

Prior to analyses, we converted slope and aspect to linear gradients (Roberts 1986). We then applied a range adjustment (0.0–1.0) to each dataset to remove large differences in scale among the variables (Sneath and Sokal 1973, Legendre and Legendre 1998). We used the "rankindex" function in Program R's vegan package for all ecosites with $\geq$30 vegetation survey points to select the most appropriate distance measure (Euclidean, Manhattan, Bray-Curtis, Gower, or Jaccard) for each dataset using Spearman's rank correlation coefficients (Oksanen et al. 2017). When differences in Spearman's rank correlation coefficients were $\geq$0.10 among the distance measures, we used the highest ranking distance measurement in our CAPs. When differences in Spearman's rank correlation coefficients among the distance measures were <0.10, we calculated the Euclidean distance between each pair of variables for use in our CAPs. We present the percent variation explained by ecosite for each scale per study area (Oksanen et al. 2008). When the percent of variation explained by ecosite was $\geq$0.20, we conducted permutational one-way Analysis of Variance (ANOVAs) to test for homogeneity of multivariate dispersion across ecosites (999 permutations) (Gijbels and Omelka 2013). We considered $P \leq 0.05$ to be statistically significant. When conditions were similar across ecosites within study areas (constrained variance $\leq$ 0.20 and $P \leq 0.05$), we linked warbler and vireo demographic information to a single STM for the study area.

Bird Survey Methods and Analyses

Point Counts

From 6 March to 6 July in 2013 and 24 March to 24 June in 2014, we conducted point count sampling at all four study areas to estimate warbler and vireo occupancy and density in relation to the structural and compositional vegetation characteristics of each study site. We created a grid network of points with 400 x 400 m spacing (originating from a random starting point) across each study site. At each point count location, we used a double-observer approach whereby two trained surveyors independently recorded the distances to all singing male warblers and singing male vireos detected within a 100-m fixed-radius circle over a 5-min sampling period (Laake et al. 2011, Collier et al. 2012, Farrell et al. 2013). We recorded distance to birds as 0–25 m, 26–50 m, 51–75 m, and 76–100 m. With few exceptions, we conducted three double-observer point count surveys at each point between sunrise and 13:00 over the course of each warbler and vireo breeding season, resulting in six total surveys per point ($\bar{x}$ = 5.8 ± 0.6 surveys). We did not conduct point count surveys during inclement weather (e.g., excessive rain or wind $\geq$20 km/h) or other conditions that could inhibit our ability to detect target species.

For occupancy modeling, we created detection/non-detection histories for each survey point. We used occupancy models for each study area with occurrence (ψ) and detection (p) parameters, and the vegetation variables we hypothesized to cause variation in warbler and vireo occurrence (see below) using the "unmarked" package in R (Fiske and Chandler 2011, Fiske et al. 2017). We selected this approach instead of creating multi-season occupancy models because preliminary analyses showed that including year as a covariate in our models did not improve model fit (A. M. Long, unpublished data). Similarly, accounting for variation in p did not improve model fit for warbler and vireo occupancy (A. M. Long, unpublished data). As such, we held p constant and varied ψ for the purposes of this report. We ranked our study area-specific occupancy models according to Akaike's Information Criterion (AIC) and we considered all models with ΔAIC < 2 as plausible (Burnham and Anderson 2002). We used chi-square goodness-of-fit tests to evaluate model fit (Fiske et al. 2017, Fiske and Chandler 2017). We calculated the 95% confidence intervals (CI) for predicted warbler and vireo occupancy for all plausible models (Burnham and Anderson 2002). We then examined the extent of overlap among the CIs to determine the potential statistical or biological significance of each relationship and we identified points or zones in habitat conditions that caused a shift (i.e., thresholds) in the predicted probability of warbler and vireo occupancy within each study area.

We used conventional distance sampling (CDS) in Program DISTANCE v. 7.1 (Thomas et al. 2010) to estimate warbler and vireo densities within each of our study areas. CDS assumes that detections at the location of the observer are certain and that the ability of the observer to detect individuals of their focal species decreases with increasing distance from the point (Buckland et al. 2001). CDS methods incorporate distance information into a detection function that identifies the probability of detection and adjusts raw bird counts accordingly (Buckland et al. 2001). We fit detection function models that included: (1) a uniform key function with a cosine series expansion (i.e., Fourier series), (2) a half-normal key function with cosine and hermite polynomial series expansions, and (3) a hazard-rate key function with cosine and simple polynomial series expansions. For simplicity, we did not include covariates when modeling the detection functions. We ranked detection function models according to Akaike's Information Criterion adjusted for small sample sizes (AIC_c) and considered all models with $\Delta AIC_c < 2$ as plausible (Sugiura 1978, Burnham and Anderson 2002). We then visually assessed plots of models fit to histograms and used chi-square goodness-of-fit tests to evaluate model fit. If all plausible models had good fit, we considered model simplicity (i.e., few parameters), and coefficients of variation (CV) and 95% confidence interval widths (CI) for the density estimates to highlight best fit models. We used the midpoint distance of each distance band (i.e., 0–25 m, 26–50 m, 51–75 m, 76–100 m) to represent the distance between birds and observers in all analyses (Thompson and LaSorte 2008), and we pooled data across years because our intent was to focus on avian responses to vegetation, not temporal variation in avian demographics.

We then used the global detection functions for each study area and species combination to estimate species' densities at each study area and at each point count location within study areas. We used point-scale estimates to fit a series of linear models using vegetation variables we hypothesized to cause variation in warbler and vireo densities (see below). We used Akaike's Information Criterion adjusted for small sample sizes (AIC_c) to rank models and we determined the relative support for each model using ΔAIC_c and Akaike Weights (w_i) (Sugiura 1978, Burham and Anderson 2002). We considered models with $\Delta AIC_c \leq 2.0$ equally plausible. We used the regression coefficients estimated from the best fit models to predict point-scale warbler and vireo density in relation to the vegetation variables included in the best fit models. We then calculated the 95% confidence intervals (CI) for predicted warbler and vireo densities to examine the extent of variation around the predicted values (Burnham and Anderson 2002). We examined the extent of overlap among the CIs to determine the potential statistical or biological significance of each relationship and identified points or zones in habitat conditions that caused a shift in avian densities (i.e., thresholds).

Territory Mapping and Monitoring

Starting on 11 March in 2013 and 13 March in 2014, we conducted transect surveys at all four study areas to record locations of singing male warblers and vireos, which we used to relocate birds during subsequent territory mapping and monitoring visits. To ensure complete survey coverage during transect surveys, we created a grid network of points with 200 x 200 m spacing (originating from a random starting point) across each study site. We walked from point to point at a 1 km/h pace from sunrise to 13:00 and marked the locations of singing male warblers and vireos with a Garmin GPS unit (within 5–10 m accuracy). We conducted transect surveys at each study site 2–3 times per week until behavioral observations indicated that warblers and vireos had established territories or we had conducted transect surveys on the study site for at least one month (adjusting for the approximate start date of each species' breeding season) with no warbler or vireo detections.

From 18 March to 4 August in 2013 and 13 March to 5 August in 2014, we mapped and monitored warblers and vireos at Balcones and Kerr. We also mapped and monitored warblers at Possum Kingdom from 27 March to 5 June 2013 and vireos at Wichita Mountains from 30 April to 28 July 2013 and 17 April to 1 July 2014. Due to logistical constraints, we did not map warblers at Possum Kingdom in 2014. We visited the locations of each singing male warbler or vireo detected during our transect surveys for one hour every 3–5 days for the duration of the warbler and vireo breeding seasons. We delineated territories by recording locations of individual male warblers and vireos during each observation period. We used a GPS unit to mark warbler and vireo locations every two minutes, recording up to 30 points in one hour (Barg et al. 2005). If a singing male was present for over four weeks in an area, we considered that area an established territory. We ceased mapping a territory when adults no longer exhibited breeding activity.

We used our warbler and vireo location points to construct minimum convex polygons (MCPs) for each monitored territory (ArcGIS 10.3). We only constructed MCPs, which represented the minimum spatial extent used by each territorial male, for all males with $\geq$15 location points recorded over the course of a breeding season. We established vegetation survey locations within each territorial boundary, which we used to examine the influence of vegetation species structure and composition on warbler and vireo pairing and fledging success (methods described below). While territory mapping, we monitored the reproductive status of each focal male warbler and vireo. We defined pairing success as the presence of a female within a focal male's territory and fledging success as the presence of $\geq$1 fledged young <2 weeks old interacting with the male or female within a paired male's territorial boundaries (see also Nest Searching and Monitoring below). Because we used the same methodology across sites, we are confident in assuming that any error in assigning reproductive outcomes to territories was similar across sites.

We developed *a priori* models including vegetation variables hypothesized to cause variation in warbler and vireo pairing and fledging success (see below). We used a generalized linear model approach to determine which variables best predicted warbler and vireo pairing and fledging success. We used Akaike's Information Criterion adjusted for small sample sizes (AIC_c) to rank models and we determined the relative support for each model using ΔAIC_c and Akaike Weights (w_i) (Sugiura 1978, Burham and Anderson 2002). We considered models with $\Delta AIC_c \leq 2.0$ equally plausible. We used the regression coefficients estimated from the best fit models to predict warbler and vireo pairing and fledging success. We then calculated the 95% confidence intervals (CI) for each predicted warbler and vireo response variable to examine the extent of variation around the predicted values (Burnham and Anderson 2002). We examined the extent of overlap among the CIs to determine the potential statistical or biological significance of each relationship and identified points or zones in habitat conditions that caused a shift in our avian responses variables (i.e., thresholds).

Nest Searching and Monitoring

From 18 March to 4 August in 2013 and 13 March to 5 August in 2014, we searched for and monitored warbler and vireo nests at Balcones and Kerr. We also searched for warbler nests at Possum Kingdom from 27 March to 5 June 2013 and we searched for and monitored vireo nests at Wichita Mountains from 30 April to 28 July 2013 and 17 April to 1 July 2014. Using behavioral cues that signify breeding (i.e., alarm calls, carrying nest material or food, singing on the nest), we searched all monitored warbler and vireo territories for nests every 3–5 days, spending no longer than one hour in each territory per visit. We checked the status of each nest every 2–3 days until the nest failed or fledged young. We used a nest mirror, binoculars, or direct observations to determine the contents of warbler and vireo nests, choosing the method that caused the least disturbance to the nest and nearby vegetation. When a nest failed, we monitored the territory for another nesting attempt. If we suspected that a nest had fledged, we searched the territory for fledglings every 3–5 days for two weeks or until we located a fledgling(s) to confirm nest success. We considered a nest successful if it fledged $\geq$1 young.

Given small sample sizes, we were not able to analyze nest data for warblers. However, we developed *a priori* models including vegetation variables hypothesized to cause variation in vireo nest success (see below). We also developed *a priori* models including vegetation variables hypothesized to cause variation in vireo daily nest survival, as calculated using the logistic exposure method described by Shaffer (2004) (see below). While nest success is identified as a binary variable (0 = unsuccessful, 1 = successful), the logistic exposure method examines nest survival during intervals between nest checks and accounts for varying interval lengths (i.e., exposure). We excluded all nests with unknown fates from nest success and daily nest survival analyses.

We used a generalized linear model approach to determine which variables best predicted vireo nest success and daily nest survival. We used Akaike's Information Criterion adjusted for small sample sizes (AIC_c) to rank models and we determined relative support of each model using ΔAIC_c and Akaike Weights (w_i) (Sugiura 1978, Burham and Anderson 2002). We considered models with $\Delta AIC_c < 2.0$ equally plausible. We used the regression coefficients estimated from the best fit model to predict vireo nest success and daily nest survival. We then calculated the 95% confidence intervals (CI) for each predicted vireo response variable to examine the extent of variation around the predicted values (Burnham and Anderson 2002). We examined the extent of overlap among the CIs to determine the potential statistical or biological significance of each relationship and identified points or zones in habitat conditions that caused a shift in vireo nest success and daily nest survival (i.e., thresholds).

Vegetation Surveys

We used a modified Breeding Biology Research & Monitoring Database (BBIRD) field protocol (Martin et al. 1997) to collect vegetation data at the site-, territory-, and nest-scales. We applied a 200 x 200 m grid network across each study site to align with our point count locations. Each grid point served as the center point of the sampling area where we recorded a suite of vegetation measurements. We established a 5-m radius circle around the center point and divided the circle into four quadrants based on the four cardinal directions. At the center point and at points 5 m away in each cardinal direction, we estimated percent canopy cover (woody vegetation >2 m) to the nearest 10% using a tubular densiometer. At each point, we also estimated the percent visual obstruction of a range pole by woody cover to the nearest 10% between 0–1 m, 1–2 m, and 2–3 m high. Within each quadrant, we visually estimated the percent woody (<2 m) of the three most dominant species to the nearest 10%. We also estimated percent herbaceous cover and percent bare ground within each quadrant to the nearest 10%.

We conducted territory-scale vegetation surveys at all study areas to determine how the vegetation characteristics described above influenced warbler and vireo pairing and fledging success. We established vegetation measurement locations at randomly placed grid points across each minimum convex polygon (MCP) at 30–50 m, depending on the size of the individual territory. This resulted in 3–10 grid points per territory. We recorded territory-scale vegetation measurements using the same protocol as described for site-scale vegetation surveys above.

We conducted nest-scale vegetation surveys at Wichita Mountains, Balcones, and Kerr to determine how the vegetation characteristics described above influenced vireo nest success and daily nest survival. We recorded vegetation measurements at all active nests that contained ≥1 host or cowbird egg or young. We recorded nest-scale vegetation measurements using the same protocol as we used at the site- and territory-scales, but used the nest as the center point.

For each vegetation survey point at the site-, territory-, and nest scales, we calculated (1) mean percent canopy cover (all tree species combined), (2) mean percent shrub cover (all shrub species combined), (3) mean percent visual obstruction in each height class (i.e., 0–1 m, 1–2 m, 2–3 m), (4) mean percent herbaceous cover, and (5) mean percent bare cover. We also calculated species-specific mean canopy cover and species-specific mean shrub cover for each vegetation survey point. For descriptive purposes, we present means and standard deviations of all vegetation variables with >30 observations for successful and unsuccessful territories and nests. We also conducted t-tests, Analyses Of Variance (ANOVAs), and Tukey's Honest Significant Difference tests (when t-test or ANOVAs suggested statistically significant differences at $\alpha = 0.05$) to compare site-, territory-, and nest scale vegetation metrics across ecosites for all variables with >30 observations (Zar 1999), which we present in Appendix D. We also used the vegetation data as explanatory variables for our models of avian density, pairing success, fledging success, nest success, and daily nest survival.

Vegetation Variable Reduction

Our vegetation surveys resulted in >100 possible metrics at the site-, territory-, and nest-scales, and while each variable represented a biologically justified relationship between the vegetation metrics and our avian responses (e.g., Smith 2011, Morgan 2012, Marshall et al. 2013, Pope et al. 2013, Long 2014), our sample sizes were low for some variables and we anticipated that some of our vegetation variables were highly correlated, which can lead to bias in regression coefficient estimates, and therefore, inaccurate model results. Our initial variable lists included all general structural vegetation metrics with a sample size >30 (e.g., mean percent canopy cover, mean percent shrub cover). We then used frequency distributions at each spatial scale (with data separated by study area and associations with warblers or vireos) to determine which plant species comprised >90% of the percent canopy cover and percent shrub cover data, and we excluded all other plant species from our datasets. Next, we used Pearson's correlation coefficient (r) to measure the strength of linear correlations between each pair of retained vegetation variables. When vegetation variables were highly correlated ($-0.60 \leq r \geq 0.60$), we selected one variable per pair of highly correlated variables to retain in our datasets. In cases when a general vegetation variable (e.g., mean percent canopy cover) was highly correlated with a species-specific vegetation variable (e.g., mean percent shin oak canopy cover), we retained the general vegetation metric in our dataset; we had no instance where a species-specific variable was highly correlated with another species-specific variable. To confirm that we had removed multicollinearity among our vegetation variables, we conducted step-wise variance inflation factor tests (VIFs) for the retained variables at each spatial scale and we excluded variables with VIF > 5.0 from our datasets. We used RANK analyses to determine how variance was partitioned across the remaining variables (Wildi 2013), and we used all variables that explained 70–80% of the variance in our datasets to construct our final candidate model sets for avian density, pairing success, fledging success, nest success, and daily nest survival. As a final data reduction step, we excluded all vegetation variables with highly skewed distributions whereby >90% of the survey points had <20% coverage of the metric.

Linking Avian Responses to STMs

We quantified the characteristics of each general vegetation variable (i.e., mean percent canopy cover, mean percent shrub cover, mean percent herbaceous cover, and mean percent bare ground) and the most frequently observed species-specific vegetation metrics (see below) relative to fire frequency (i.e., number of years since the last prescribed burn or wildfire) at each study area. For many of our points, data describing the fire frequency did not extend beyond eight years prior to our study. As such, we represented locations with no recent fire history (i.e., >7 years since the last prescribed burn or wildfire) or no known fire history as an "8" for analyses purposes. Using regression, we modeled each vegetation characteristic as a linear and quadratic response to time since burn. We compared model fit using the "anova" function in R and selected the best fit model based on the resulting *P* value ($\alpha = 0.05$) from chi-square tests used to determine when a reduction in the residual sum of squares was statistically significant. We used the regression coefficients estimated from the best fit models to predict each vegetation response in relation to time since burn. We then calculated the 95% confidence intervals (CI) for each predicted response to examine the extent of variation around the predicted values (Burnham and Anderson 2002). Depending on the available data at each scale per study area, we used avian response graphs to describe the characteristics of each vegetative community within our state and transition models (STMs) as a function of known time since last burn. We used the predicted relationships to extrapolate vegetation characteristics that extended beyond the fire frequencies represented at our study areas (>8 years post burn). We then associated each avian response to the corresponding vegetation continuum identified within each state of our STMs.

RESULTS

State-and-Transition Model Development

Based on primary field names (e.g., Clay Loam, as described above), each study area was composed of 3–7 ecological sites (Table 1). In Table 1, we provide the proportions of land area for each ecological site category within the Major Land Resource Areas (MLRAs), the proportions of land area for each ecological site category within potential warbler habitat (Collier et al. 2012) and potential vireo habitat (USGS 2013) within each MLRA, and the proportions of land area for each ecological site category within our 2013 and 2014 study areas. The proportions of land area represented by each ecological site are slightly different between years because we modified our study sites in year two to capture greater variability in avian responses to vegetation structure and composition. "Other" includes all ecosites that were not represented at any of our study sites within the MLRA.

Ninety-nine percent of site-scale, 98% of territory-scale, and 98% of nest-scale vegetation points at Wichita Mountains were located in Boulder Ridge Savannah (Table 2). As such, we linked vireo demographic information to a single state-and-transition model (STM), using the hypothesized vegetation dynamics within the Boulder Ridge Savannah ecosite, for the Wichita Mountains study area. We did not conduct Canonical Analysis of Principal Coordinates (CAP; Legendre and Anderson 1999, Anderson and Willis 2003) at the territory-scale for warblers at Possum Kingdom or at the nest-scale for vireos at Balcones due to small sample sizes for most ecosites (Table 2). Because we found limited differences (Spearman's rank correlation coefficients <0.10) among the distance measures (Euclidean, Manhattan, Bray-Curtis, Gower, or Jaccard) at each spatial scale (Table 2), we used Euclidian distance as the basis for all site-, territory-, and nest-scale CAPs. Though we do not present the data in this report, we conducted CAPs using all distance measures and we conducted traditional Redundancy Analyses using Euclidean distance; we found that our results were consistent regardless of the distance measure or analysis technique at all spatial scales (A. M. Long, unpublished data). Ecosite explained 6–12% of the constrained variation in our site-, territory-, and nest-scale datasets at Possum Kingdom, Balcones, and Kerr (Figs. 4–6, Table 2). As such, we did not conduct permutational ANOVAs. Instead, we linked warbler and vireo demographic information to a single STM for each study area. We used the hypothesized vegetation dynamics for the STM with the largest number of survey points to help inform our study area-specific STMs (i.e., Clay Loam at Possum Kingdom, Low Stony Hill at Balcones, and Low Stony Hill at Kerr; Table 2).

Table 1. Proportions of land area for each ecological site category within the Major Land Resource Areas included in our examination of compatibility of fire management for two endangered songbirds, the golden-cheeked warbler (Setophaga chrysoparia; hereafter warbler) and black-capped vireo (Vireo atricapilla; hereafter vireo), at the Wichita Mountains Wildlife Refuge and adjacent Fort Sill Military Reservation in Oklahoma (Wichita Mountains), Possum Kingdom State Park in Texas (Possum Kingdom), Balcones Canyonlands National Wildlife Refuge and nearby private lands in Texas (Balcones), and Kerr Wildlife Management Area in Texas (Kerr). We also provide the proportions of land area for each ecological site category within potential warbler habitat (Collier et al. 2012) and potential vireo habitat (USGS 2013) in each MLRA, and we provide the proportions of land area for each ecological site category within our 2013 and 2014 study areas.

Study Area	Ecosites[1,2]	Major Land Resource Area	Potential Warbler Habitat	Potential Vireo Habitat	2013	2014
Wichita Mountains	Boulder Ridge Savannah	0.17	—	0.08	0.98	0.84
	Clay Loam	0.23	—	0.17	0.02	0.02
	Other	0.34	—	0.42	0.00	0.00
	Unknown	0.26	—	0.33	0.00	0.14
Possum Kingdom	Clay Loam	0.08	0.22	0.09	0.57	0.59
	Low Stony Hill	0.04	0.10	0.03	0.05	0.05
	Other	0.07	0.33	0.34	0.00	0.00
	Redland	0.15	0.11	0.07	0.01	0.01
	Sandstone Hill	0.30	0.19	0.15	0.00	0.02
	Sandy Loam	0.34	0.15	0.32	0.02	0.00
	Unknown	0.02	0.00	0.00	0.35	0.33
Balcones	Adobe	0.24	0.27	0.20	0.09	0.20
	Blackland	0.01	0.00	0.03	0.02	0.00
	Clay Loam	0.11	0.05	0.10	0.02	0.02
	Low Stony Hill	0.19	0.23	0.28	0.75	0.66
	Other	0.08	0.03	0.04	0.00	0.00
	Redland	0.11	0.09	0.13	0.02	0.02
	Shallow	0.09	0.06	0.03	0.01	0.04
	Steep Rocky	0.16	0.27	0.17	0.09	0.06
	Unknown	0.01	0.00	0.02	0.00	0.00

Kerr	Clay Loam	0.11	0.02	0.14	0.07	0.07
	Low Stony Hill	0.46	0.46	0.48	0.45	0.44
	Other	0.29	0.16	0.32	0.00	0.00
	Redland	0.07	0.20	0.01	0.08	0.09
	Steep Rocky	0.07	0.16	0.05	0.40	0.40
	Unknown	0.00	0.00	0.00	0.00	0.00

[1] As defined by the United States Department of Agriculture's Forest Service Natural Resource Conservation Service's Ecological Site Description System for Rangeland and Forestland portal: https://esis.sc.egov.usda.gov

[2] "Other" includes all ecosites that were not represented at any of our study sites within the Major Land Resource Area

Table 2. Results of Canonical Analysis of Principal Coordinates used to identify the total amount of variance in our vegetation datasets explained by ecosite at the site-, territory-, and nest-scales within each study area (Wichita Mountains: Wichita Mountains Wildlife Refuge and adjacent Fort Sill Military Reservation in Oklahoma; Possum Kingdom: Possum Kingdom State Park in Texas; Balcones: Balcones Canyonlands National Wildlife Refuge and nearby private lands in Texas; Kerr: Kerr Wildlife Management Area in Texas).

Study Area	Scale[1]	Ecosites	Sample Size[2]	Correlation Coeffients[3]	Constrained Variance	Unconstrained Variance
Wichita Mountains	Site	Boulder Ridge Savannah	263	—	—	—
		Clay Loam	2			
	Territory	Boulder Ridge Savannah	840	—	—	—
		Clay Loam	11			
		Loamy Bottomland	4			
	Nest	Boulder Ridge Savannah	298	—	—	—
		Clay Loam	2			
		Loamy Bottomland	3			
Possum Kingdom	Site	Clay Loam	202	0.09–0.14	26.68 (0.12)	204.48 (0.88)
		Low Stony Hill	18			
		Redland	117			
		Sandstone Hill	6			
		Sandy Loam	3			
	Territory	Clay Loam	63	—	—	—
		Redland	15			
Balcones	Site	Adobe	143	0.11–0.19	37.2 (0.06)	577.1 (0.94)
		Blackland	2			
		Clay Loam	18			
		Low Stony Hill	607			

		Redland	16			
		Shallow	21			
		Steep Rocky	67			
	Territory	Adobe	221	0.13–0.23	114.7 (0.09)	1099.6 (0.91)
		Clay Loam	2			
		Low Stony Hill	1295			
		Redland	4			
		Shallow	14			
		Steep Rocky	91			
	Nest	Low Stony Hill	356	—	—	—
		Shallow	1			
		Steep Adobe	16			
Kerr	Site	Clay Loam	34	0.07–0.09	19.9 (0.06)	304.1 (0.94)
		Low Stony Hill	210			
		Redland	42			
		Steep Rocky	187			
	Territory	Clay Loam	6	0.07–0.11	36.25 (0.07)	464.90 (0.93)
		Low Stony Hill	311			
		Redland	182			
		Steep Rocky	324			
	Nest	Clay Loam	1	0.09–0.12	16.18 (0.09)	164.86 (0.91)
		Low Stony Hill	84			
		Redland	61			
		Steep Rocky	35			

[1] We conducted all nest-scale analyses using data collected at black-capped vireo (*Vireo atricapilla*) nests. We did not find any nests at Possum Kingdom.
[2] We excluded ecosites with ≤30 vegetation survey points from our analyses
[3] Range of Spearman's correlation coefficients for Euclidean, Manhattan, Bray-Curtis, Gower, and Jaccard distance measures

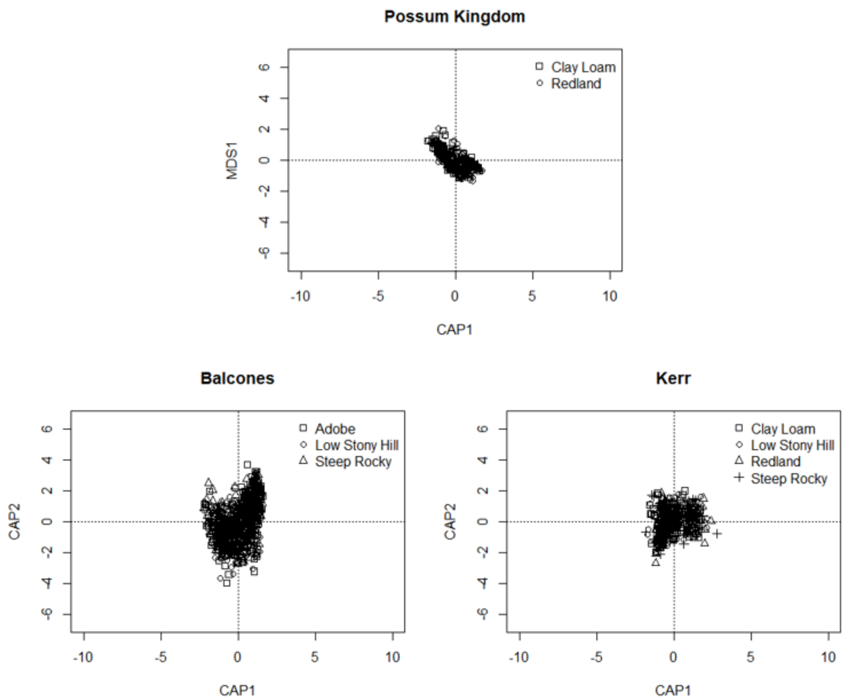

Figure 4. Results of Canonical Analysis of Principal Coordinates (CAP) used to identify the total amount of variance in our vegetation datasets explained by ecosite at the site-scale within each study area (Possum Kingdom: Possum Kingdom State Park in Texas; Balcones: Balcones Canyonlands National Wildlife Refuge and nearby private lands in Texas; Kerr: Kerr Wildlife Management Area in Texas). Also see Table 2.

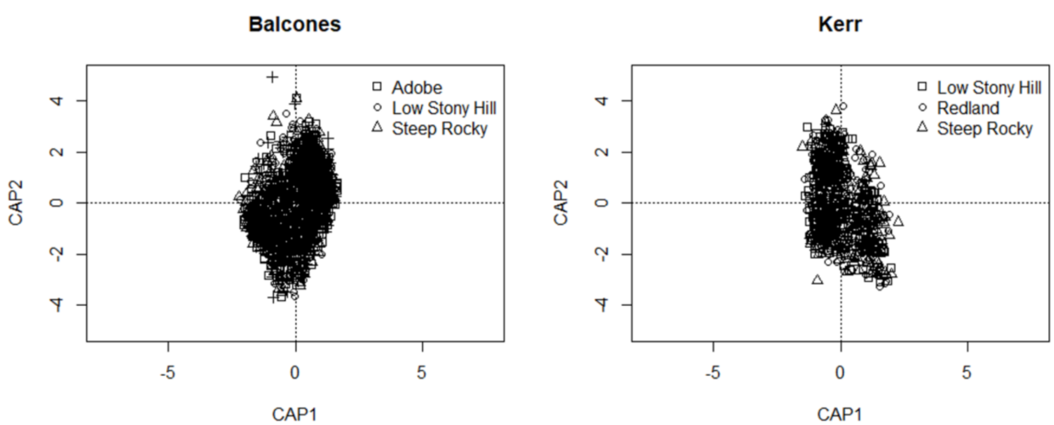

Figure 5. Results of Canonical Analysis of Principal Coordinates (CAP) used to identify the total amount of variance in our vegetation datasets explained by ecosite at the territory-scale within each study area (Balcones: Balcones Canyonlands National Wildlife Refuge and nearby private lands in Texas; Kerr: Kerr Wildlife Management Area in Texas). Also see Table 2.

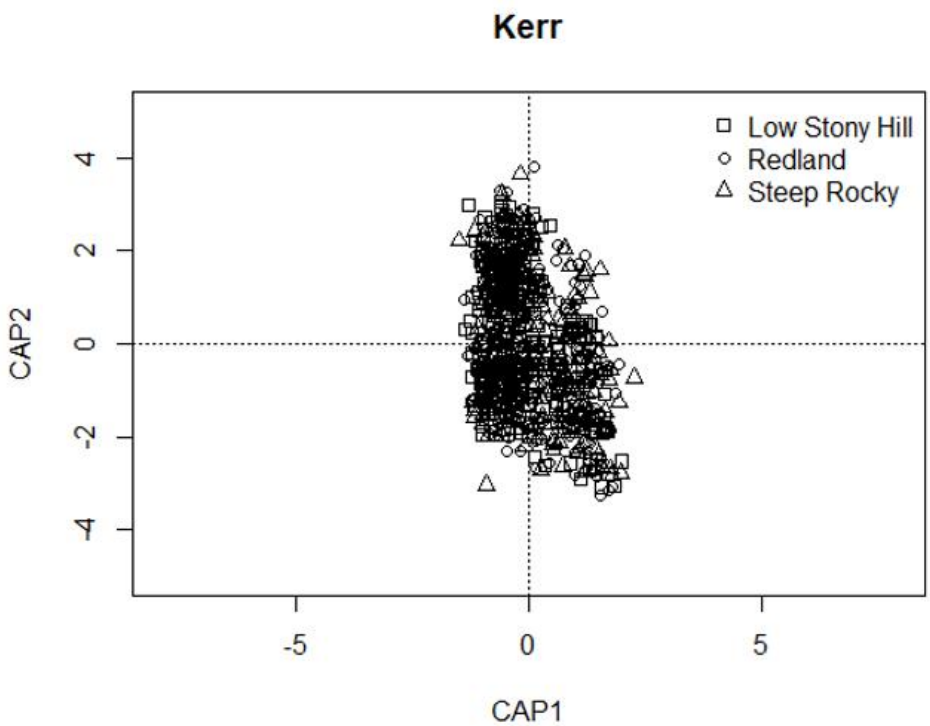

Figure 6. Results of Canonical Analysis of Principal Coordinates used to identify the total amount of variance in our nest vegetation data explained by ecosite at the Kerr Wildlife Management Area in Texas. Also see Table 1.

Vegetation Variable Reduction

Prior to quantifying avian occupancy, density, pairing success, fledging success, nest success, and daily nest survival in relation to vegetation structure and composition, we conducted a variable reduction procedure with data separated by study area and associations with warblers or vireos (i.e., warbler or vireo detected within 100 m of the vegetation survey point). After excluding highly correlated variables with sample size >30 (Tables 3 and 4), Variance Inflation Factors (VIFs) ranged from 1.05–2.20 across all study areas at the site-scale, 1.02–4.76 at the territory-scale, and 1.09–3.12 at the nest-scale. We found a small number of exceptions (i.e., VIF $\geq$ 5.0) and we excluded those variables from further analyses. These included mean percent herbaceous cover at the site-scale for vireos at Balcones, mean percent canopy cover at the nest-scale for vireos at Wichita Mountains, and mean percent post oak shrub cover at the nest-scale for vireos at Wichita Mountains. Table 5 identifies the final variables we used for our models, which are highlighted gray.

Table 3. Pairs of vegetation variables associated with (i.e., detection within 100 m of the vegetation survey point) golden-cheeked warblers (*Setophaga chrysoparia*) at Possum Kingdom State Park in Texas (Possum Kingdom), Balcones Canyonlands National Wildlife Refuge and nearby private lands in Texas (Balcones), and Kerr Wildlife Management Area in Texas (Kerr) that had sufficient samples sizes (n > 30) and Pearson's correlation coefficient $-0.60 \leq r \geq 0.60$. From each pair, we retained Variable A for further analyses.

Study Area	Scale	Variable A[1]	Variable B[1]	*r*
Possum Kingdom	Site	Canopy cover	Ashe juniper canopy cover	0.80
		Herbaceous cover	Bare ground	-0.93
	Territory	Herbaceous cover	Bare ground	-0.96
Balcones	Site	Canopy cover	Ashe juniper canopy cover	0.73
		Herbaceous cover	Bare ground	-0.76
		Shrub cover	Shin oak shrub cover	0.73
		Visual obstruction (0–1 m)	Visual obstruction (1–2 m)	0.63
	Territory	Herbaceous cover	Bare ground	-0.61
		Shrub cover	Shin oak shrub cover	0.61
		Visual obstruction (0–1 m)	Visual obstruction (1–2 m)	0.71
Kerr	Site	Canopy cover	Ashe juniper canopy cover	0.88
		Herbaceous cover	Bare ground	-0.74
		Visual obstruction (1–2 m)	Visual obstruction (2–3 m)	0.64
	Territory	Canopy cover	Ashe juniper canopy cover	0.72
		Herbaceous cover	Bare ground	-0.76
		Shrub cover	Bare ground	-0.66

[1] Mean percentages

Table 4. Pairs of vegetation variables associated with (i.e., detection within 100 m of the vegetation survey point) black-capped vireos (Vireo atricapilla) at Wichita Mountains Wildlife Refuge and adjacent Fort Sill in Oklahoma (Wichita Mountains), Balcones Canyonlands National Wildlife Refuge and nearby private lands in Texas (Balcones), and Kerr Wildlife Management Area in Texas (Kerr) that had sufficient samples sizes ($n > 30$) and Pearson's correlation coefficient $-0.60 \leq r \geq 0.60$. From each pair, we retained Variable A for further analyses.

Study Area	Scale	Variable A[1]	Variable B	*r*
Wichita Mountains	Site	Herbaceous cover	Bare ground	-0.74
		Shrub cover	Blackjack oak shrub cover	0.72
	Territory	Herbaceous cover	Bare ground	0.66
		Shrub cover	Blackjack oak shrub cover	-0.70
		Visual obstruction (2–3 m)	Visual obstruction (1–2 m)	0.70
	Nest	Shrub cover	Blackjack oak shrub cover	0.75
		Visual obstruction (2–3 m)	Visual obstruction (1–2 m)	0.64
Balcones	Site	Canopy cover	Ashe juniper canopy cover	0.77
		Canopy cover	Visual obstruction (2–3 m)	0.64
		Herbaceous cover	Bare ground	-0.77
		Visual obstruction (0–1 m)	Visual obstruction (1–2 m)	0.67
	Territory	Canopy cover	Ashe juniper canopy cover	0.72
		Shrub cover	Shin oak shrub cover	0.75
		Shrub cover	Visual obstruction (0–1 m)	0.62
		Visual obstruction (0–1 m)	Shin oak shrub cover	0.62
		Visual obstruction (0–1 m)	Visual obstruction (1–2 m)	0.72
	Nest	Shrub cover	Shin oak shrub cover	0.65
Kerr	Site	Herbaceous cover	Bare ground	-0.70
		Visual obstruction (1–2 m)	Visual obstruction (0–1 m)	0.61
		Visual obstruction (1–2 m)	Visual obstruction (2–3 m)	0.69

Territory	Canopy cover	Live oak canopy cover	0.63
	Visual obstruction (0–1 m)	Visual obstruction (1–2 m)	0.76
Nest	Canopy cover	Live oak canopy cover	0.77
	Shrub cover	Bare ground	-0.63
	Visual obstruction (0–1 m)	Visual obstruction (1–2 m)	0.63

[1] Mean percentages

Table 5. Results of the variable reduction procedure used to identify which vegetation metrics were included analyses of avian density, pairing success, fledging success, nest success and daily nest survival for golden-cheeked warblers (*Setophaga chrysoparia*; GCWA) and black-capped vireos *(Vireo atricapilla*; BCVI) at the Wichita Mountains Wildlife Refuge and adjacent Fort Sill Military Reservation in Oklahoma (Wichita Mountains), Possum Kingdom State Park in Texas (Possum Kingdom), Balcones Canyonlands National Wildlife Refuge and nearby private lands in Texas (Balcones), and Kerr Wildlife Management Area in Texas (Kerr). Variables that are not highlighted as bold text were excluded from further analyses because they were highly correlated with another scale-specific variable within the study area based on Pearson's correlation coefficients and Variance Inflation Factors ($-0.60 \leq r \geq 0.60$ or VIF > 5.0; identified by *), explained 70–80% of the variance in the datasets based on RANK analyses (identified by †), or had insufficient data distributions (i.e., >90% of the vegetation survey points had <20% coverage of the metric; identified by ‡).

Study Area	Bird Species	Site-scale Variables with >30 Observations[1]	Territory-scale Variables with >30 Observations[1]	Nest-scale Variables with >30 Observations[1]
Wichita Mountains	BCVI	**Bare ground*** Blackjack oak shrub cover* **Canopy cover** **Herbaceous cover** **Shrub cover** Visual obstruction (0–1 m)† Visual obstruction (1–2 m)†	Bare ground* Blackjack oak canopy cover* Blackjack oak shrub cover† **Canopy cover** Eastern red cedar canopy cover† Eastern red cedar shrub cover‡ Flameleaf sumac shrub cover† Gum bumelia shrub cover‡ Hackberry shrub cover‡ Herbaceous cover† Post oak shrub cover‡ **Shrub cover** Visual obstruction (0–1 m)† Visual obstruction (1–2 m)* Visual obstruction (2–3 m) †	**Bare ground** Blackjack oak canopy cover* Blackjack oak shrub cover† Canopy cover* Eastern red cedar canopy cover† Eastern red cedar shrub cover‡ Hackberry shrub cover† Herbaceous cover† Post oak canopy cover* Post oak shrub cover† **Shrub cover** Visual obstruction (0–1 m)† Visual obstruction (1–2 m)* Visual obstruction (2–3 m)†
Possum Kingdom	GCWA	Ashe juniper canopy cover* Bare ground* **Canopy cover** **Herbaceous cover** **Shrub cover**	**Ashe juniper canopy cover** Bare ground* **Canopy cover** Herbaceous cover† **Shin oak canopy cover**	—

			Shrub cover	
Balcones	GCWA	Ashe juniper canopy cover* Ashe juniper shrub cover‡ Bare ground* **Canopy cover** Herbaceous cover† Shin oak shrub cover* **Shrub cover** Visual obstruction (0–1 m)† Visual obstruction (1–2 m)* Visual obstruction (2–3 m)‡	Ashe juniper canopy cover‡ Ashe juniper shrub cover† Bare ground* Canopy cover* Elbowbush shrub cover† **Herbaceous cover** Live oak canopy cover‡ Live oak shrub cover‡ Shin oak canopy cover‡ Shin oak shrub cover* **Shrub cover** Texas ash shrub cover‡ Texas oak canopy cover‡ Texas oak shrub cover† Visual obstruction (0–1 m)† Visual obstruction (1–2 m) * Visual obstruction (2–3 m)†	—
Balcones	BCVI	Ashe juniper canopy cover* Bare ground **Canopy cover** Herbaceous cover* **Shin oak shrub cover** **Shrub cover** Visual obstruction (0–1 m)† Visual obstruction (1–2 m)* Visual obstruction (2–3 m)*	Agarita shrub cover‡ Ashe juniper canopy cover† Ashe juniper shrub cover* Bare ground† **Canopy cover** Cedar elm shrub cover‡ Elbowbush shrub cover‡ Flameleaf sumac canopy cover‡ Herbaceous cover‡ Live oak canopy cover† Shin oak canopy cover† Shin oak shrub cover*	Ashe juniper canopy cover† Ashe juniper shrub cover‡ **Bare ground** **Canopy cover** Elbowbush shrub cover† Flameleaf sumac canopy cover‡ Flameleaf sumac shrub cover‡ **Herbaceous cover** Live oak canopy cover‡ Live oak shrub cover† Shin oak canopy cover†

			Shrub cover Texas oak canopy cover† Texas oak shrub cover‡ Texas persimmon shrub cover‡ Visual obstruction (0–1 m)* Visual obstruction (1–2 m)* Visual obstruction (2–3 m)†	Shin oak shrub cover* **Shrub cover** Texas oak canopy cover‡ Texas oak shrub cover† Texas persimmon shrub cover† **Visual obstruction (0–1 m)** Visual obstruction (1–2 m)† **Visual obstruction (2–3 m)**
Kerr	GCWA	Ashe juniper canopy cover* Ashe juniper shrub cover‡ Bare ground* **Canopy cover** **Herbaceous cover** Shrub cover† **Visual obstruction (0–1 m)** Visual obstruction (1–2 m)† Visual obstruction (2–3 m)*	Ashe juniper canopy cover* Ashe juniper shrub cover† Bare ground* **Canopy cover** Herbaceous cover* Live oak canopy cover‡ Live oak shrub cover† Shin oak canopy cover‡ **Shrub cover** Texas oak canopy cover† Visual obstruction (0–1 m)† Visual obstruction (1–2 m) ‡ Visual obstruction (2–3 m)†	—
Kerr	BCVI	Ashe juniper shrub cover† Bare ground* **Canopy cover** **Herbaceous cover** Live oak canopy cover† **Live oak shrub cover** **Shrub cover** Visual obstruction (0–1 m)* Visual obstruction (1–2 m)†	Agarita shrub cover‡ Ashe juniper canopy cover† Ashe juniper shrub cover‡ Bare ground† **Canopy cover** Eastern redbud shrub cover Flameleaf sumac shrub cover† Hackberry shrub cover‡ Herbaceous cover*	Ashe juniper shrub cover‡ Bare ground* Canopy cover† Eastern redbud shrub cover† Flameleaf sumac shrub cover† Herbaceous cover† Live oak canopy cover* Live oak shrub cover† Shin oak canopy cover†

Visual obstruction (2–3 m)*	Live oak canopy cover*	**Shin oak shrub cover**
	Live oak shrub cover†	**Shrub cover**
	Shin oak canopy cover†	Visual obstruction (0–1 m)†
	Shin oak shrub cover	Visual obstruction (1–2 m)*
	Shrub cover	Visual obstruction (2–3 m)‡
	Texas persimmon shrub cover‡	
	Visual obstruction (0–1 m)†	
	Visual obstruction (1–2 m)*	
	Visual obstruction (2–3 m)†	

[1] Mean percentages

Bird Surveys

Point Counts

We surveyed 523 point count locations across our study areas (Table 6). We detected warblers at 224 points, vireos at 281 points, and both species at 98 points (Table 6). The best fit models for warbler occupancy at Possum Kingdom and Balcones included percent canopy cover (Table 7). At both study areas, the predicted probability of warbler occupancy increased with increasing canopy cover (Fig. 7). However, at Possum Kingdom we found more variability in the predicted probability of warbler occupancy at higher values of percent canopy cover (Fig. 7). Warbler detection probabilities were 0.45 and 0.46 at Possum Kingdom and Balcones, respectively. Chi-square tests using bootstrapped data indicated that both models had adequate fit ($P = 0.47$ at Possum Kingdom and $P = 0.97$ at Balcones). The best fit model for warbler occupancy at Kerr included percent herbaceous cover (Table 7). The next best fit model described the relationship between percent canopy cover and occupancy and had ΔAIC only slightly greater than 2.0, so we also considered this a plausible model for warbler occupancy at Kerr (Table 7). At Kerr, the predicted probability of warbler occupancy decreased with increasing herbaceous cover and increased with increasing percent canopy cover (Fig. 8). Warbler detection probability at Kerr was similar to Possum Kingdom and Balcones ($p = 0.49$). Chi-square tests using bootstrapped data indicated that both models had adequate fit ($P = 0.80$ for percent herbaceous cover and $P = 0.95$ for percent canopy cover).

The best fit models for vireo occupancy at Wichita Mountains and Balcones included percent shrub cover and the best fit model for vireo occupancy at Kerr included percent herbaceous cover (Table 7). At Wichita Mountains and Balcones, the predicted probability of vireo occupancy increased with increasing percent shrub cover and at Kerr the predicted probability of vireo occupancy increased with increasing percent herbaceous cover (Figs. 9, 10). However, overlapping confidence intervals suggested that this relationship may only be significant when percent shrub cover is <40% (Fig. 9). Vireo detection probability ranged from 0.45–0.69 across study areas. Chi-square tests using bootstrapped data indicated that all three models had adequate fit ($P = 0.47$ at Wichita Mountains, $P = 0.70$ at Balcones, and $P = 0.96$ at Kerr).

At all study areas, uniform key functions with cosine adjustments provided the best fit models for estimating warbler and vireo density (Fig. 11, Table 8). All of the best fit models had coefficients of variation (CV) <20%, with the exception of warbler density at Possum Kingdom (CV = 38%), where many point count stations were located in vegetation that was recently burned. Detection probabilities varied by study area, ranging from 39–71% for warblers and 40–61% for vireos. The effective detection radii also varied by study area, ranging from 57–77 m for warblers and 43–65 m for vireos.

Table 6. Number of point count locations we surveyed for golden-cheeked warblers (*Setophaga chrysoparia*; hereafter warblers) and black-capped vireos (*Vireo atricapilla*; hereafter vireos) at Wichita Mountains Wildlife Refuge and adjacent Fort Sill Military Reservation in Oklahoma (Wichita Mountains), Possum Kingdom State Park in Texas (Possum Kingdom), Balcones Canyonlands National Wildlife Refuge and nearby private lands in Texas (Balcones), and Kerr Wildlife Management Area in Texas (Kerr).

Study Area	Points Surveyed	Points with Warblers	Points with Vireos[1]	Points with Both Species
Wichita Mountains	99	0	71	0
Possum Kingdom	79	18	3	1
Balcones	222	137	105	53
Kerr	123	69	102	44

[1] We excluded Possum Kingdom vireos from occupancy and density analyses due to small sample sizes

Table 7. Results of model selection procedure for golden-cheeked warbler (Setophaga chrysoparia; GCWA) and black-capped vireo (Vireo atricapilla; BCVI) occupancy at Wichita Mountains Wildlife Refuge and adjacent Fort Sill Military Reservation in Oklahoma (Wichita Mountains), Possum Kingdom State Park in Texas (Possum Kingdom), Balcones Canyonlands National Wildlife Refuge and nearby private lands in Texas (Balcones), and Kerr Wildlife Management Area in Texas (Kerr).

Study Area	Bird Species	Model[1]	K^2	AIC[3]	ΔAIC[4]	w_i^5
Wichita Mountains	BCVI	Shrub cover	3	642.96	0.00	0.69
		Bare ground	3	646.56	3.60	0.11
		Herbaceous cover	3	646.68	3.72	0.11
		Canopy cover	3	647.16	4.20	0.09
Possum Kingdom	GCWA	Canopy cover	3	216.33	0.00	0.92
		Shrub cover	3	221.35	5.02	0.07
		Herbaceous cover	3	225.27	8.93	0.01
Balcones	GCWA	Canopy cover	3	1199.75	0.00	1.00
		Shrub cover	3	1229.98	30.23	0.00
Balcones	BCVI	Shrub cover	3	997.17	0.00	0.94
		Canopy cover	3	1003.01	5.84	0.05
		Shin oak shrub cover	3	1005.43	8.25	0.02
Kerr	GCWA	Herbaceous cover	3	638.17	0.00	0.76
		Canopy cover	3	640.49	2.32	0.23
		Visual obstruction (0–1 m)	3	654.73	16.56	0.00

Kerr	BCVI	Herbaceous cover	3	795.30	0.00	0.86
		Shrub cover	3	800.12	4.82	0.08
		Canopy cover	3	800.91	5.61	0.05
		Live oak shrub cover	3	804.48	9.19	0.01

[1] Mean percentages
[2] Number of parameters in the model
[3] Akaike's Information Criteria
[4] Akaike's Information Criteria relative to the best fit model
[5] Model weight

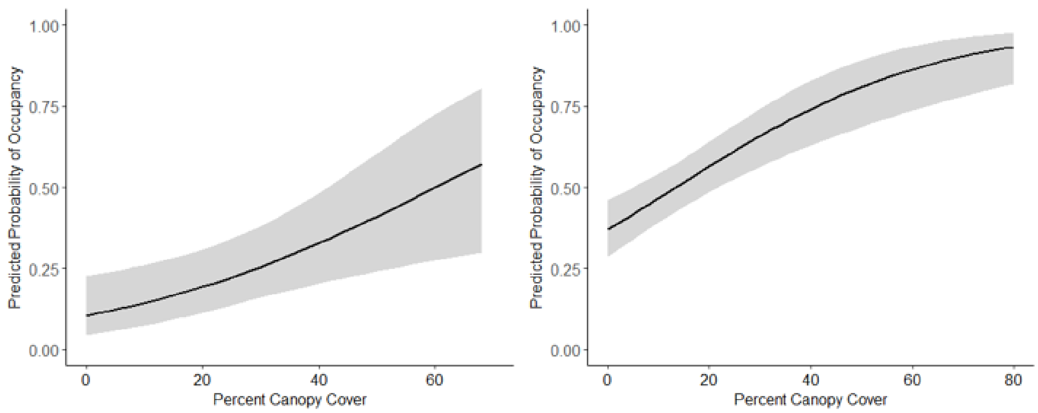

Figure 7. Predicted probability of golden-cheeked warbler (*Setophaga chrysoparia*) occupancy in relation to percent canopy cover at Possum Kingdom State Park in Texas (left) and Balcones Canyonlands National Wildlife Refuge and nearby private lands in Texas (right).

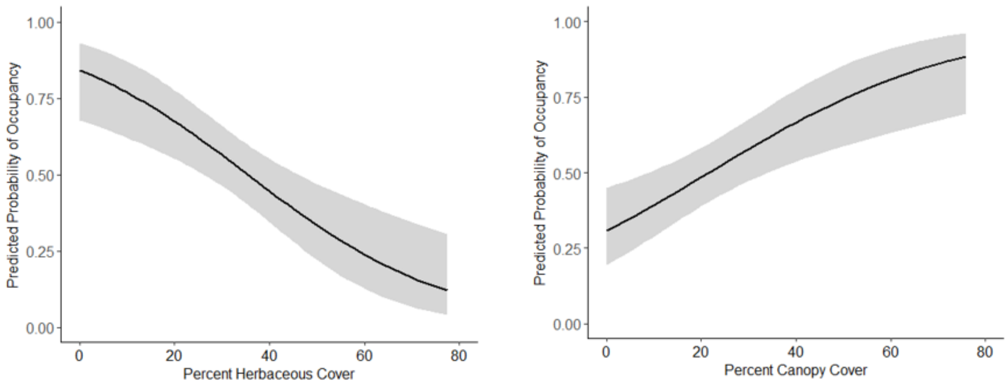

Figure 8. Predicted probability of golden-cheeked warbler (*Setophaga chrysoparia*) occupancy in relation to percent herbaceous cover and percent canopy cover at Kerr Wildlife Management Area in Texas.

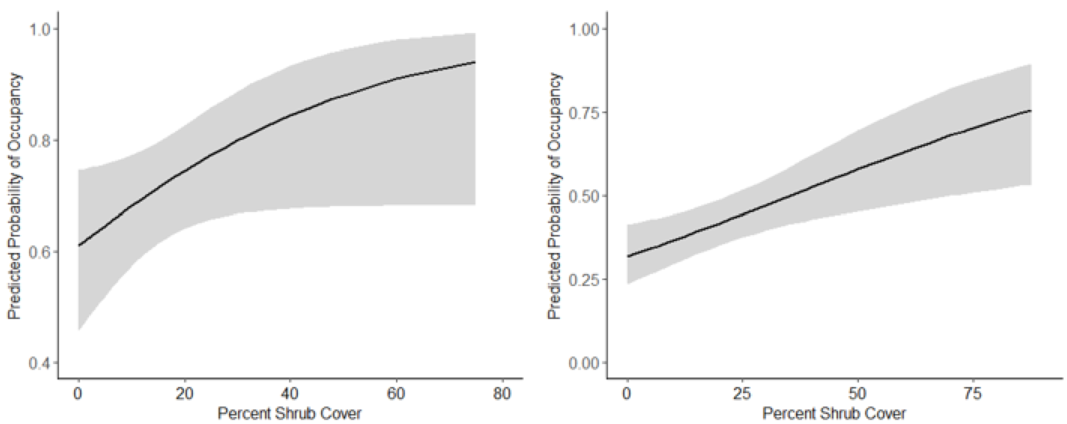

Figure 9. Predicted probability of black-capped vireo (*Vireo atricapilla*) occupancy in relation to percent shrub cover at Wichita Mountains Wildlife Refuge and adjacent Fort Sill in Oklahoma (left) and Balcones Canyonlands National Wildlife Refuge and nearby private lands in Texas (right).

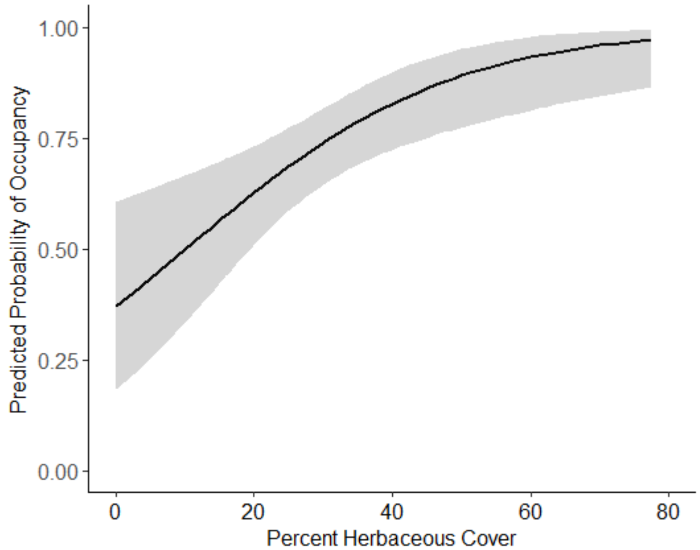

Figure 10. Predicted probability of black-capped vireo (*Vireo atricapilla*) occupancy in relation to percent herbaceous cover at Kerr Wildlife Management Area in Texas.

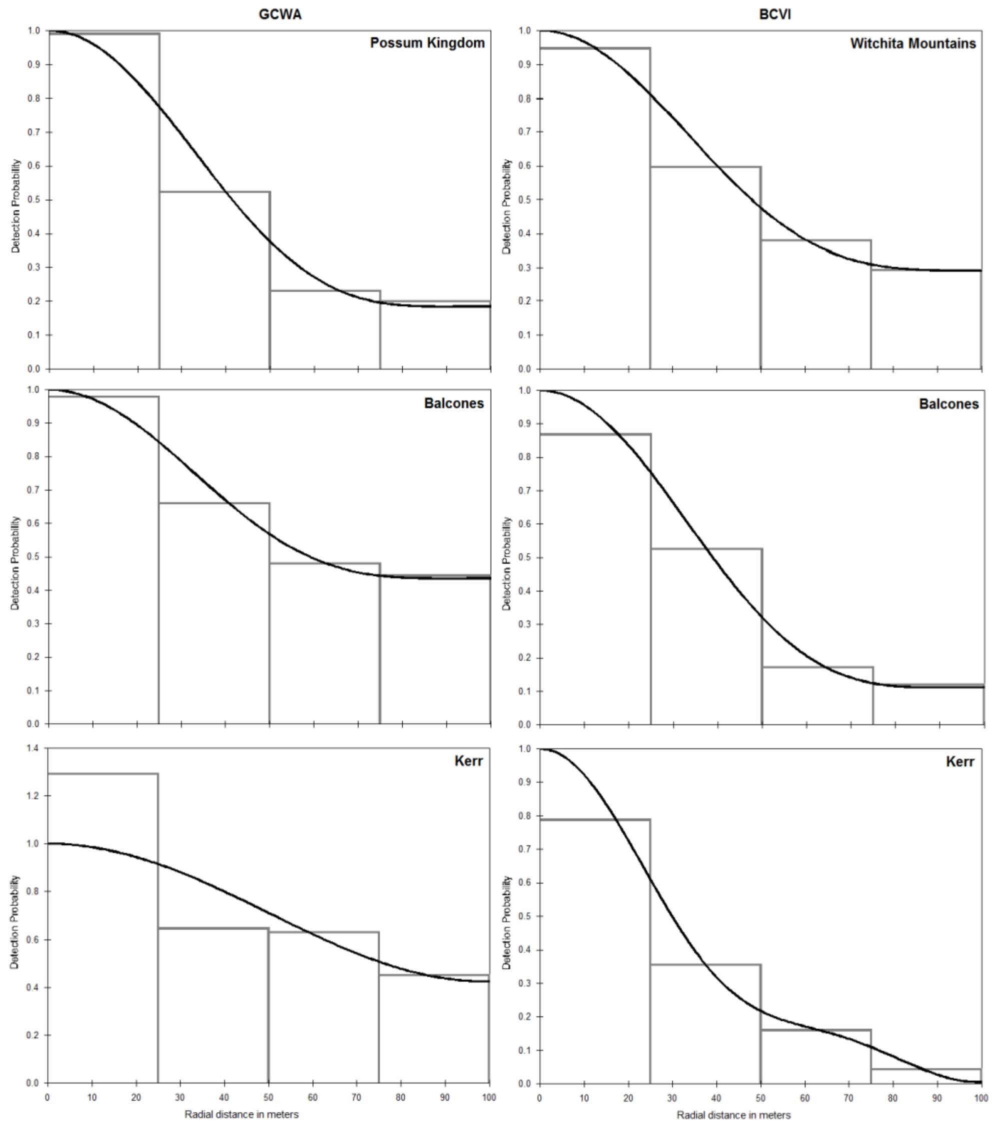

Figure 11. Detection-probability histograms from top distance models for golden-cheeked warblers (*Setophaga chrysoparia*; GCWA) and black-capped vireos (*Vireo atricapilla*; BCVI) at the Wichita Mountains Wildlife Refuge and adjacent Fort Sill Military Reservation in Oklahoma (Wichita Mountains), Possum Kingdom State Park in Texas (Possum Kingdom), Balcones Canyonlands National Wildlife Refuge and nearby private lands in Texas (Balcones), and Kerr Wildlife Management Area in Texas (Kerr).

Table 8. Results of model selection procedure for golden-cheeked warbler (*Setophaga chrysoparia*; GCWA) and black-capped vireo (*Vireo atricapilla*; BCVI) detection probability at Wichita Mountains Wildlife Refuge and adjacent Fort Sill Military Reservation in Oklahoma (Wichita Mountains), Possum Kingdom State Park in Texas (Possum Kingdom), Balcones Canyonlands National Wildlife Refuge and nearby private lands in Texas (Balcones), and Kerr Wildlife Management Area in Texas (Kerr). Asterisks (*) indicate the best fit detection function based on ΔAIC_c, histograms, chi-square goodness-of-fit tests, number of parameters, and coefficients of variation and 95% confidence interval widths for density estimates.

Study Area	**Bird Species**	**Model**[1]	K[2]	**Log Liklihood**	**AIC$_c$**[3]	**ΔAIC$_c$**[4]	w_i[5]
Wichita Mountains	BCVI	HR Cosine	2	-589.93	1183.89	0.00	0.25
		HR Simple	2	-589.93	1183.89	0.00	0.25
		HN Cosine	2	-589.94	1183.90	0.01	0.25
		Uniform Cosine*	2	-590.06	1184.16	0.26	0.22
		HN Hermite	1	-593.92	1189.85	5.96	0.01
Possum Kingdom	GCWA	Uniform Cosine*	2	-85.24	174.69	0.00	0.24
		HN Cosine	2	-85.27	174.74	0.05	0.23
		HR Cosine	2	-85.35	174..90	0.22	0.21
		HR Simple	2	-85.35	174.90	0.22	0.21
		HN Hermite	1	-87.16	176.39	1.70	0.10
Balcones	GCWA	HN Cosine	2	-533.82	1071.68	0.00	0.36
		Uniform Cosine*	2	-533.95	1071.96	0.25	0.32
		HR Cosine	3	-533.75	1073.56	1.88	0.14
		HR Simple	3	-533.83	1073.71	2.03	0.13
		HN Hermite	1	-537.04	1076.09	4.42	0.04
Balcones	BCVI	Uniform Cosine*	2	-385.12	774.28	0.00	0.45
		HN Cosine	3	-384.56	775.20	0.92	0.29
		HR Cosine	3	-385.29	776.66	2.38	0.14
		HR Simple	2	-386.45	776.95	2.67	0.12
		HN Hermite	1	-393.12	788.26	13.98	0.00
Kerr	GCWA	HN Cosine	3	-313.38	632.86	0.00	0.29
		Uniform Cosine*	1	-315.80	633.63	0.77	0.20
		HR Simple	2	-314.84	633.74	0.88	0.19
		HR Cosine	2	-314.84	633.74	0.88	0.19
		HN Hermite	1	-316.14	634.29	1.44	0.14
Kerr	BCVI	Uniform Cosine*	3	-729.38	1464.80	0.00	0.33
		HN Cosine	3	-729.38	1464.80	0.00	0.33
		HR Simple	3	-729.38	1464.80	0.00	0.33
		HN Hermite	1	-734.25	1470.50	5.74	0.02

		HR Cosine	2	-735.23	1474.48	9.71	0.00

[1] Detection functions HN = half normal and HR = hazard rate
[2] Number of parameters in the model
[3] Akaike's Information Criteria
[4] Akaike's Information Criteria relative to the best fit model
[5] Model weight

Table 9. Results of model selection procedure for golden-cheeked warbler (*Setophaga chrysoparia*; GCWA) and black-capped vireo (*Vireo atricapilla*; BCVI) density at Wichita Mountains Wildlife Refuge and adjacent Fort Sill Military Reservation in Oklahoma (Wichita Mountains), Possum Kingdom State Park in Texas (Possum Kingdom), Balcones Canyonlands National Wildlife Refuge and nearby private lands in Texas (Balcones), and Kerr Wildlife Management Area in Texas (Kerr).

Study Area	**Bird Species**	**Model**[1]	K^2	**Log Liklihood**	**AIC$_c$**[3]	**ΔAIC$_c$**[4]	w_i[5]
Wichita Mountains	BCVI	Shrub cover	2	-85.98	187.96	0.00	0.50
		Herbaceous cover	2	-86.33	188.67	0.70	0.35
		Canopy cover	2	-87.90	191.80	3.83	0.07
		Bare ground	2	-87.90	191.80	3.84	0.07
Possum Kingdom	GCWA	Canopy cover	2	-30.38	52.75	0.00	0.80
		Shrub cover	2	-31.74	55.47	2.72	0.20
Balcones	GCWA	Canopy cover	2	-1658.47	3308.95	0.00	0.92
		Shrub cover	2	-1660.90	3313.79	4.84	0.08
Balcones	BCVI	Shrub cover	2	-142.31	276.63	0.00	0.66
		Canopy cover	2	-142.99	277.99	1.36	0.34
Kerr	GCWA	Canopy cover	2	-1.20	-5.59	0.00	0.99
		Shrub cover	2	-6.15	4.31	9.90	0.01
Kerr	BCVI	Herbaceous cover	2	-245.09	506.17	0.00	0.91
		Shrub cover	2	-247.37	510.74	4.57	0.09
		Canopy cover	2	-252.63	521.27	15.09	0.00
		Live oak shrub cover	2	-253.14	522.29	16.11	0.00

[1] Mean percentages
[2] Number of parameters in the model
[3] Akaike's Information Criteria
[4] Akaike's Information Criteria relative to the best fit model
[5] Model weight

Estimated warbler density at the site-scale was 0.14 birds/ha (CI: 0.07–0.29) at Possum Kingdom, 0.20 birds/ha (CI: 0.15–0.28) at Balcones, and 0.19 birds per ha (CI: 0.14–0.25) at Kerr. Estimated vireo density at the site-scale was 0.59 birds/ha (CI: 0.44–0.79) at Wichita Mountains, 0.28 birds/ha (CI: 0.21–0.37) at Balcones, and 1.53 birds per ha (CI: 1.20–1.95) at Kerr. The best fit models for point-scale warbler density at Possum Kingdom, Balcones, and Kerr included percent canopy cover (Table 9). At all study areas, point-scale warbler density increased with increasing canopy cover. However, overlapping confidence intervals indicated that none of the relationships were statistically significant. The best fit models for point-scale vireo density at Wichita Mountains included percent shrub cover and percent herbaceous cover. The best fit models for point-scale vireo density at Balcones included percent shrub cover and percent canopy cover. The best fit model for point-scale vireo density at Kerr included percent herbaceous cover (Table 9). Vireo density increased with increasing shrub cover and herbaceous cover and decreased with increasing canopy cover, but again, overlapping confidence intervals indicated that none of the relationships were statistically significant.

Pairing and Fledging Success

We mapped and monitored 10 warbler territories at Possum Kingdom, 114 warbler territories at Balcones, and 46 warbler territories at Kerr (Table 10). On average, we visited warbler territories three times during each breeding season at Possum Kingdom, 10 times during each breeding season at Balcones, and 17 times during each breeding season at Kerr. On average, we recorded 25 male warbler points per territory at Possum Kingdom, 69 male warbler points per territory at Balcones, and 117 male warbler points per territory at Kerr. Warbler pairing success ranged from 50–100% across study areas and warbler fledging success ranged from 40–72% across study areas (Table 10). We present mean percentages and standard deviations of general vegetation variables for successful and unsuccessful golden-cheeked warbler territories per study area in Appendix E. Because the number of warbler territories at Possum Kingdom was low and we were unable to monitor Possum Kingdom as frequently as our other study areas, we excluded Possum Kingdom from territory-scale warbler analyses beyond the descriptive information provided in Table 10 and Appendix E.

We mapped and monitored 215 vireo territories at Wichita Mountains, 215 vireo territories at Balcones, and 164 vireo territories at Kerr (Table 10). On average, we visited vireo territories 12 times during each breeding season at Wichita Mountains, 15 times during each breeding season at Balcones, and 14 times during each breeding season at Kerr. On average, we recorded 46 male vireo points per territory at Wichita Mountains, 94 male vireo points per territory at Balcones, and 73 male vireo points per territory at Kerr. Vireo pairing success ranged from 96–100% across study areas and vireo fledging success ranged from 59–83% across study areas (Table 10). We present means and standard deviations of general vegetation characteristics for successful and unsuccessful vireo territories per study area in Appendix E.

Given high warbler and vireo pairing success at all study sites (Table 10), we did not conduct a model selection procedure to determine which vegetation variables best predicted this avian response variable; doing so would have produced uniform and uninformative results. The best fit model for warbler fledging success at Balcones included percent shrub cover (Table 11); the predicted probability of warbler fledging success increased with increasing percent shrub cover in this study area (Fig. 12). At Kerr, two models including the main effects of percent canopy cover and percent shrub cover were equally plausible (Table 11). The predicted probability of warbler fledging success at Kerr increased with increasing percent canopy cover and decreased with increasing percent shrub cover. However, overlapping confidence intervals suggest that neither relationship is statistically significant for warbler fledging success at this study area.

Table 10. Golden-cheeked warbler (*Setophaga chrysoparia*; GCWA) and black-capped vireo (*Vireo atricapilla*; BCVI) pairing success and fledging success at Wichita Mountains Wildlife Refuge and adjacent Fort Sill Military Reservation in Oklahoma (Wichita Mountains), Possum Kingdom State Park in Texas (Possum Kingdom), Balcones Canyonlands National Wildlife Refuge and nearby private lands in Texas (Balcones), and Kerr Wildlife Management Area in Texas (Kerr).

Species	**Study Area**	**Monitored**	**Paired[1]**	**Fledged[1]**
GCWA	Possum Kingdom	10	5 (50%)	2 (40%)
	Balcones	114	104 (91%)	66 (63%)
	Kerr	46	46 (100%)	33 (72%)
BCVI	Wichita Mountains	215	215 (100%)	179 (83%)
	Balcones	215	207 (96%)	123 (59%)
	Kerr	164	163 (99%)	101 (62%)

[1] We defined pairing success as the presence of a female within the focal male's territory and fledging success as the presence of $\geq$1 fledged young <2 weeks old interacting with the male or female within the territory boundaries.

Table 11. Results of model selection procedure for golden-cheeked warbler (*Setophaga chrysoparia*; GCWA) and black-capped vireo (*Vireo atricapilla*; BCVI) fledging success (i.e., male fledged ≥1 host young) at Wichita Mountains Wildlife Refuge and adjacent Fort Sill Military Reservation in Oklahoma (Wichita Mountains), Balcones Canyonlands National Wildlife Refuge and nearby private lands in Texas (Balcones), and Kerr Wildlife Management Area in Texas (Kerr).

Study Area	**Bird Species**	**Model[1]**	**K[2]**	**Log liklihood**	**AIC$_c$[3]**	**ΔAIC$_c$[4]**	**w_i[5]**
Wichita Mountains	BCVI	Shrub cover	2	-94.14	180.29	0.00	0.95
		Canopy cover	2	-97.09	186.18	5.90	0.05
Balcones	BCVI	Canopy cover	2	-139.28	270.56	0.00	0.61
		Shrub cover	2	-139.71	271.43	0.87	0.39
Kerr	BCVI	Canopy cover	2	-107.67	207.34	0.00	0.46
		Shin oak shrub cover	2	-108.15	208.30	0.96	0.28
		Shrub cover	2	-108.24	208.48	1.13	0.26
Balcones	GCWA	Shrub cover	2	-66.24	124.47	0.00	0.82
		Herbaceous cover	2	-67.78	127.55	3.08	0.18
Kerr	GCWA	Canopy cover	2	-27.34	46.68	0.00	0.51
		Shrub cover	2	-27.36	46.73	0.05	0.49

[1] Mean percentages
[2] Number of parameters in the model
[3] Akaike's Information Criteria corrected for small sample sizes
[4] AIC$_c$ relative to the best fit model
[5] Model weight

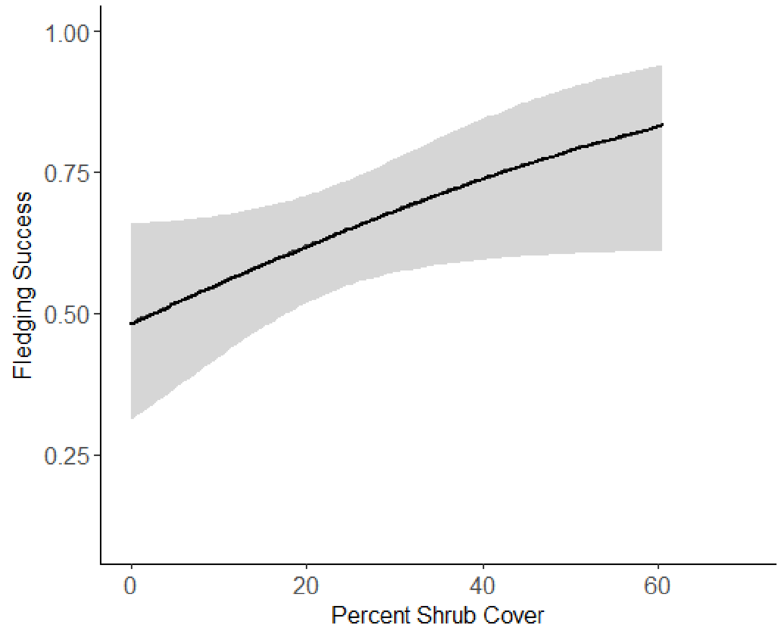

Figure 12. Predicted probability of golden-cheeked warbler (*Setophaga chrysoparia*) fledging success in relation to percent shrub cover at Balcones Canyonlands National Wildlife Refuge and adjacent private lands in Texas.

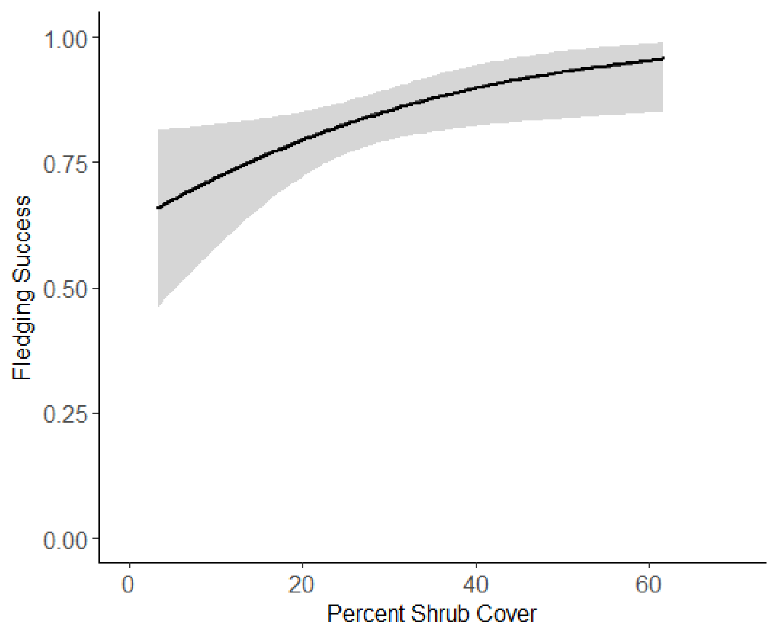

Figure 13. Predicted probability of black-capped vireo (*Vireo atricapilla*) fledging success in relation to percent herbaceous cover at Wichita Mountains Wildlife Refuge and adjacent Fort Sill in Oklahoma.

The best fit model for vireo fledging success at Wichita Mountains included percent shrub cover (Table 11); the predicted probability of vireo fledging success increased with increasing percent shrub cover in this study area (Fig. 13). At Balcones, two models including the main effects of percent canopy cover and percent shrub cover were equally plausible (Table 11). The predicted probability of vireo fledging success at Balcones decreased with increasing percent canopy cover and slightly increased with increasing percent shrub cover. However, overlapping confidence intervals suggest that neither relationship is statistically significant for vireo fledging success at this study area. At Kerr, three models including the main effects of percent canopy cover, percent shin oak shrub cover, and percent shrub cover were equally plausible (Table 11). The predicted probability of vireo fledging success at Kerr increased with increasing percent canopy cover, slightly increased with increasing percent shin oak shrub cover, and slightly decreased with increased percent shrub cover. However, overlapping confidence intervals suggest that none of these relationships were statistically significant for vireo fledging success at this study area.

Nest Success and Daily Nest Survival

We located and monitored 25 warbler nests at Balcones and six warbler nests at Kerr. We did not locate any warbler nests at Possum Kingdom. Seventy-two percent of warbler nests (n = 18 warbler nests) fledged $\geq$1 host young at Balcones and 83% of warbler nests (n = 5 warbler nests) fledged $\geq$1 host young at Kerr. We did not observe cowbird eggs or young in any warbler nests at Balcones or Kerr. For descriptive purposes, we provide means and standard deviations for all general vegetation variables at successful and unsuccessful warbler nests, defined as fledging >1 host young, per study area in Appendix F. Given low sample sizes, we did not conduct analyses for warbler nest success or daily nest survival.

We located and monitored 257 vireo nests at Wichita Mountains, 342 vireo nests at Balcones, and 165 vireo nests at Kerr (Table 12). Vireo nest success ranged from 40–61% across study areas (Table 12). Six percent of vireo nests were parasitized by cowbirds at Wichita Mountains, 17% of vireo nests were parasitized by cowbirds at Balcones, and 16% of vireo nests were parasitized by cowbirds at Kerr (Table 12). Of the parasitized vireo nests, 76–95% failed (Table 12). For descriptive purposes, we provide means and standard deviations for all general vegetation variables at successful and unsuccessful vireo nests in Appendix F and we detail results for vireo nest success and daily nest survival below.

The best fit model for vireo nest success at Wichita Mountains included percent bare ground (Table 13); the predicted probability of vireo nest success decreased with increasing percent bare ground in this study area (Fig. 14). At Balcones, six models including the main effects of percent herbaceous cover, percent visual obstruction (2–3 m), percent visual obstruction (0–1 m), percent bare ground, percent canopy cover, and percent shrub cover were equally plausible (Table 13). The predicted probability of vireo nest success at Balcones decreased with increasing percent herbaceous cover, percent visual obstruction (2–3 m), percent bare ground, and percent canopy cover, and the predicted probability of vireo nest success increased with increasing percent visual obstruction (0–1 m) and percent shrub cover. However, overlapping confidence intervals suggest that none of these relationships were statistically significant for vireo nest success at this study area. At Kerr, two models including the main effects of percent shrub cover and percent shin oak shrub cover were equally plausible (Table 13). The predicted probability of vireo fledging success at Kerr decreased with increasing percentage of both metrics. However, overlapping confidence intervals suggest that neither of these relationships were statistically significant for vireo nest success at this study area.

Table 12. Black-capped vireo (*Vireo atricapilla*) nest success at Wichita Mountains Wildlife Refuge and adjacent Fort Sill Military Reservation in Oklahoma (Wichita Mountains), Possum Kingdom State Park in Texas (Possum Kingdom), Balcones Canyonlands National Wildlife Refuge and nearby private lands in Texas (Balcones), and Kerr Wildlife Management Area in Texas (Kerr).

Study Area	Number Monitored	Fledged Host Young	Number Parasitized[1]	Parasitized and Fledged Host Young[1]
Wichita Mountains	257	147 (57%)	17 (7%)	4 (24%)
Balcones	342	129 (61%)	59 (17%)	3 (5%)
Kerr	165	65 (40%)	27 (16%)	4 (15%)

[1] Black-capped vireo nests parasitized by brown-headed cowbirds (*Molothrus ater*)

Table 13. Results of model selection procedure for black-capped vireo (*Vireo atricapilla*) nest success (i.e., nest fledged ≥1 host young) at Wichita Mountains Wildlife Refuge and adjacent Fort Sill Military Reservation in Oklahoma (Wichita Mountains), Balcones Canyonlands National Wildlife Refuge and nearby private lands in Texas (Balcones), and Kerr Wildlife Management Area in Texas (Kerr).

Study Area	Model[1]	K[2]	Log liklihood[3]	AIC_c[b]	ΔAIC_c[c]	w_i[d]
Wichita Mountains	Bare ground	2	-175.5	343.01	0.00	0.85
	Shrub cover	2	-177.2	346.40	3.39	0.15
Balcones	Herbaceous cover	2	-232.55	473.09	0.00	0.23
	Visual obstruction (2–3 m)	2	-232.83	473.66	0.57	0.18
	Visual obstruction (1–2 m)	2	-232.95	473.90	0.81	0.16
	Bare ground	2	-232.97	473.95	0.86	0.15
	Canopy cover	2	-233.04	474.07	0.98	0.14
	Shrub cover	2	-233.10	474.21	1.12	0.13
Kerr	Shin oak shrub cover	2	-111.4	214.8	0.00	0.65
	Shrub cover	2	-112.0	216.1	1.25	0.35

[1] Mean percentages
[2] Number of parameters in the model
[3] Akaike's Information Criteria corrected for small sample sizes
[4] AIC_c relative to the best fit model
[5] Model weight

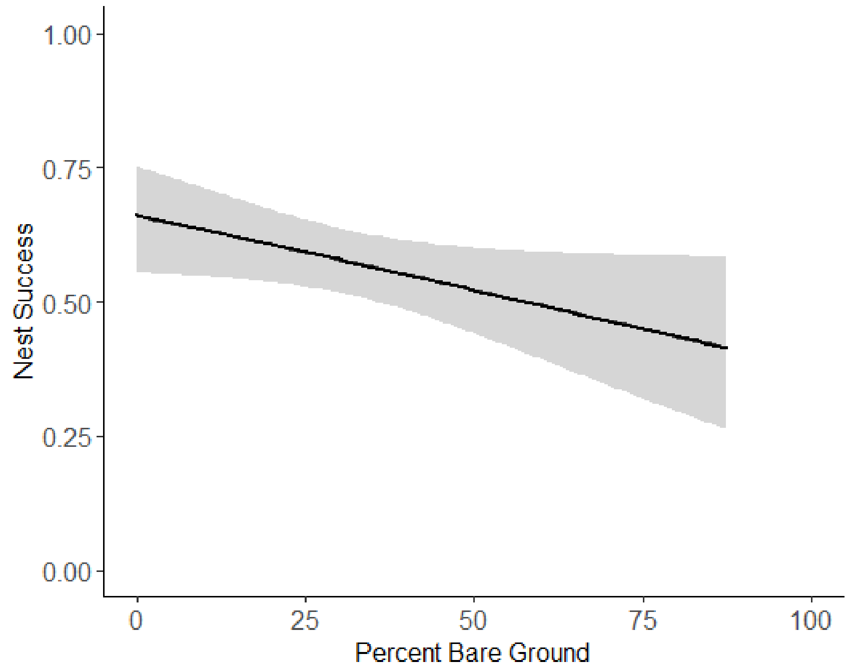

Figure 14. Predicted probability of black-capped vireo (*Vireo atricapilla*) nest success in relation to percent bare ground at Wichita Mountains Wildlife Refuge and adjacent Fort Sill in Oklahoma.

The best fit model for vireo daily nest survival at Wichita Mountains included percent bare ground (Table 14); the predicted probability of vireo daily nest survival decreased slightly with increasing percent bare ground in this study area (Fig. 15). At Balcones, six models including the main effects of percent bare ground, percent visual obstruction (0–1 m), percent shrub cover, percent visual obstruction (2–3 m), percent canopy cover, and percent herbaceous cover were equally plausible (Table 14). The predicted probability of vireo daily nest survival at Balcones decreased with increasing percent herbaceous cover, percent visual obstruction (2–3 m), percent bare ground, and percent canopy cover. However, overlapping confidence intervals suggest that none of these relationships were statistically significant for vireo nest success at this study area. At Kerr, vireo daily nest survival was best predicted by percent shin oak shrub cover (Table 14). The predicted probability of vireo daily nest survival at Kerr decreased with increasing percent shin oak shrub cover (Fig. 16).

Table 14 Results of model selection procedure for black-capped vireo (*Vireo atricapilla*) daily nest survival at Wichita Mountains Wildlife Refuge and adjacent Fort Sill Military Reservation in Oklahoma (Wichita Mountains), Balcones Canyonlands National Wildlife Refuge and nearby private lands in Texas (Balcones), and Kerr Wildlife Management Area in Texas (Kerr).

Study Area	**Model**[1]	***K***[2]	**Log liklihood**[3]	**AIC_c**[b]	**ΔAIC_c**[c]	**w_i**[d]
Wichita Mountains	Bare ground	2	-396.10	784.20	0.00	0.77
	Shrub cover	2	-397.32	786.60	2.4	0.23
Balcones	Bare ground	2	-649.62	1307.24	0.00	0.19
	Visual obstruction (0–1 m)	2	-649.73	1307.47	0.23	0.16
	Shrub cover	2	-649.75	1307.50	0.26	0.16
	Visual obstruction (2–3 m)	2	-649.75	1307.50	0.26	0.16
	Canopy cover	2	-649.75	1307.50	0.26	0.16
	Herbaceous cover	2	-649.75	1307.50	0.26	0.16
Kerr	Shin oak shrub cover	2	-291.00	574.00	0.00	0.89
	Shrub cover	2	-293.10	578.10	4.12	0.11

[1] Mean percentages
[2] Number of parameters in the model
[3] Akaike's Information Criteria corrected for small sample sizes
[4] AIC_c relative to the best fit model
[5] Model weight

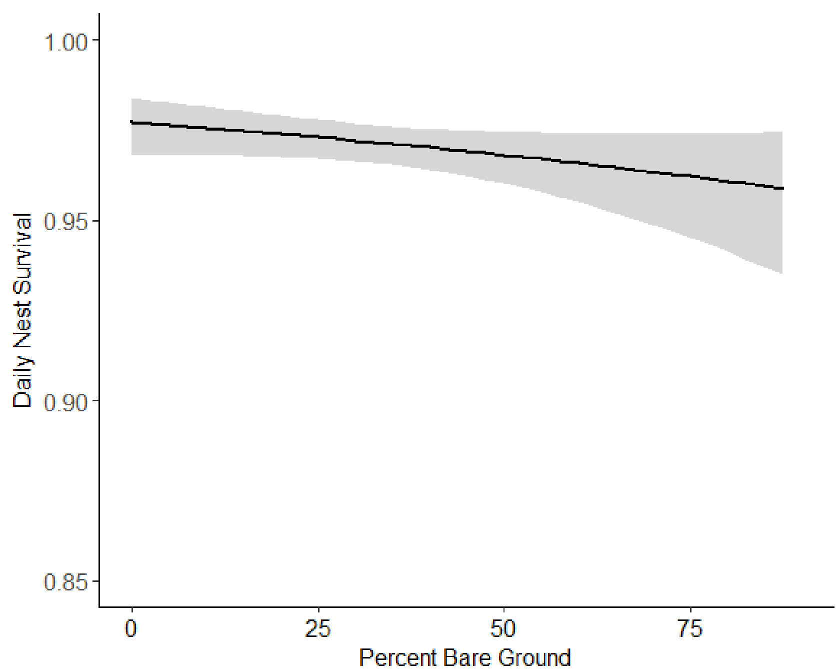

Figure 15. Predicted probability of black-capped vireo (*Vireo atricapilla*) daily nest survival in relation to percent bare ground at Wichita Mountains Wildlife Refuge and adjacent Fort Sill in Oklahoma.

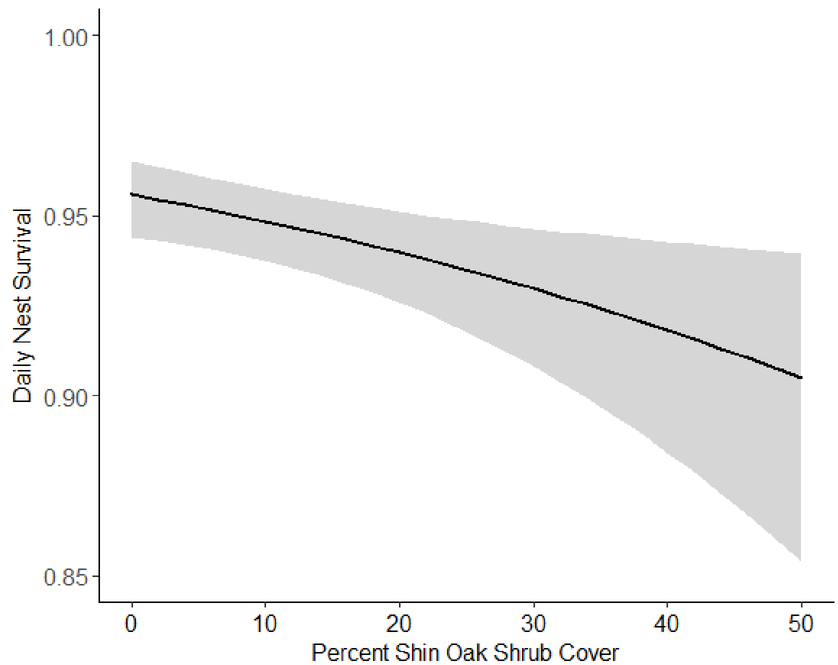

Figure 16. Predicted probability of black-capped vireo (*Vireo atricapilla*) daily nest survival in relation to percent shin oak shrub cover at Kerr Wildlife Management Area in Texas.

Linking Avian Responses to STMs

While most models exhibited substantial variation (Appendix G), site-scale predicted percent canopy cover remained stable with increasing time since burn at Wichita Mountains, increased with increasing time since burn at Possum Kingdom and Kerr, and increased at Balcones after five years post burn (Figs. 23, 24, 28). At Wichita Mountains and Kerr, predicted percent shrub cover decreased five years post burn, at Possum Kingdom it increased over time, and at Balcones it increased five years post burn (Figs. 17, 18, 23, 28). Predicted percent herbaceous cover decreased over time at Wichita Mountains and Kerr, increased over time after five years post burn at Possum Kingdom, and decreased over time after five years at Balcones (Figs. 17, 18, 23, 24, 28). Predicted percent bare ground at Wichita Mountains decreased after five years post burn and at Balcones it increased after five years post burn (Figs. 17, 18, 24). At Wichita Mountains, predicted percent blackjack and post oak canopy cover increased over time (Figs. 17, 18). At Possum Kingdom and Kerr, predicted Ashe juniper canopy cover increased over time (Figs. 23, 28). At Balcones, predicted Ashe juniper canopy cover increased after five years post burn (Fig. 24).

Again, most models at the territory-scale exhibited substantial variation (Appendix G). However, warbler territory-scale predicted percent canopy cover remained stable with increasing time since burn at Balcones and Kerr (Figs. 25, 29). Predicted percent shrub cover within warbler territories slightly increased with increasing time since burn at Balcones and decreased with increasing time since burn at Kerr (Figs. 25, 29). Predicted percent herbaceous cover within warbler territories decreased after five years post burn at Balcones and increased after five years post burn at Kerr (Figs. 25, 19). At Kerr, warbler territory-scale predicted percent bare ground decreased after five years post burn (Fig. 29). Predicted percent Ashe juniper canopy cover within warbler territories remained stable across time at Balcones and decreased over time at Kerr (Fig. 25, 29).

At Wichita Mountains, predicted percent canopy cover within vireo territories decreased after five years post burn (Fig. 19, 20). At Balcones and Kerr, predicted percent canopy within vireo territories increased after five years post burn (Figs. 26, 30). Predicted percent shrub cover within vireo territories increased over time at Wichita Mountains and Kerr and decreased over time at Balcones (Figs, 19, 20, 26, 30). Predicted percent herbaceous cover within vireo territories decreased over time at Wichita Mountains and decreased over time after five years post burn at Balcones and Kerr (Figs, 19, 20, 26, 30). Predicted bare ground within vireo territories at Wichita Mountains and Balcones increased over time after five years post burn (Figs. 19, 20, 26). At Wichita Mountains, both predicted percent blackjack oak canopy and predicted percent blackjack oak shrub cover within vireo territories increased with time since burn (Figs. 19, 20). Within vireo territories at Balcones predicted percent shin oak shrub cover decreased over time, and at Kerr predicted percent Ashe juniper canopy cover increased over time (Figs. 26, 30).

Similar to the site- and territory-scale, most models at the nest-scale exhibited substantial variation (Appendix G). However, predicted percent canopy cover at vireo nests decreased after five years post burn at Wichita Mountains and Kerr and predicted percent canopy cover increased over time at Balcones (Figs. 21, 22, 27, 31, 32). At vireo nests in Wichita Mountains and Kerr, predicted percent shrub cover increased over time, and it decreased over time at Balcones (Figs. 21, 22, 27, 32). Predicted percent herbaceous cover decreased over time at Wichita Mountains and Kerr, and it increased over time at Balcones (Figs. 21, 22, 27, 31, 32). Predicted percent bare ground increased after five years post burn at Wichita Mountains, and it increased with increasing time post burn at Kerr (Figs. 21, 22, 31, 32). At the nest scale, both predicted percent blackjack oak canopy cover and predicted percent blackjack oak shrub cover at Wichita Mountains increased over time, and the predicted percent post oak canopy cover at Wichita Mountains decreased over time (Figs. 21, 22). At Balcones, predicted percent Ashe juniper canopy increased over time at the nest scale and predicted percent shin oak shrub cover increased over time after five years post burn (Fig. 27). At Kerr, predicted Ashe juniper canopy cover, predicted shin oak canopy cover, and predicted shin oak shrub cover increased over time after five years post burn at the scale of vireo nest sites (Figs. 31, 32). In addition, at Kerr, predicted percent live oak canopy at vireo nests increased over time and predicted percent live oak shrub cover at vireo nests decreased after five years post burn (Figs. 31, 32).

In Figures 33–36, we demonstrate a multi-species, multi-response STM approach that identifies the fire frequencies necessary to predict the negative effects or enhance the positive effects of disturbance on warblers and vireos per Major Land Resource Area. While we do not present the data here, the groups identified in our STMs corresponded with the number of groups identified as optimal by K-means cluster partitioning (A. M. Long, unpublished data).

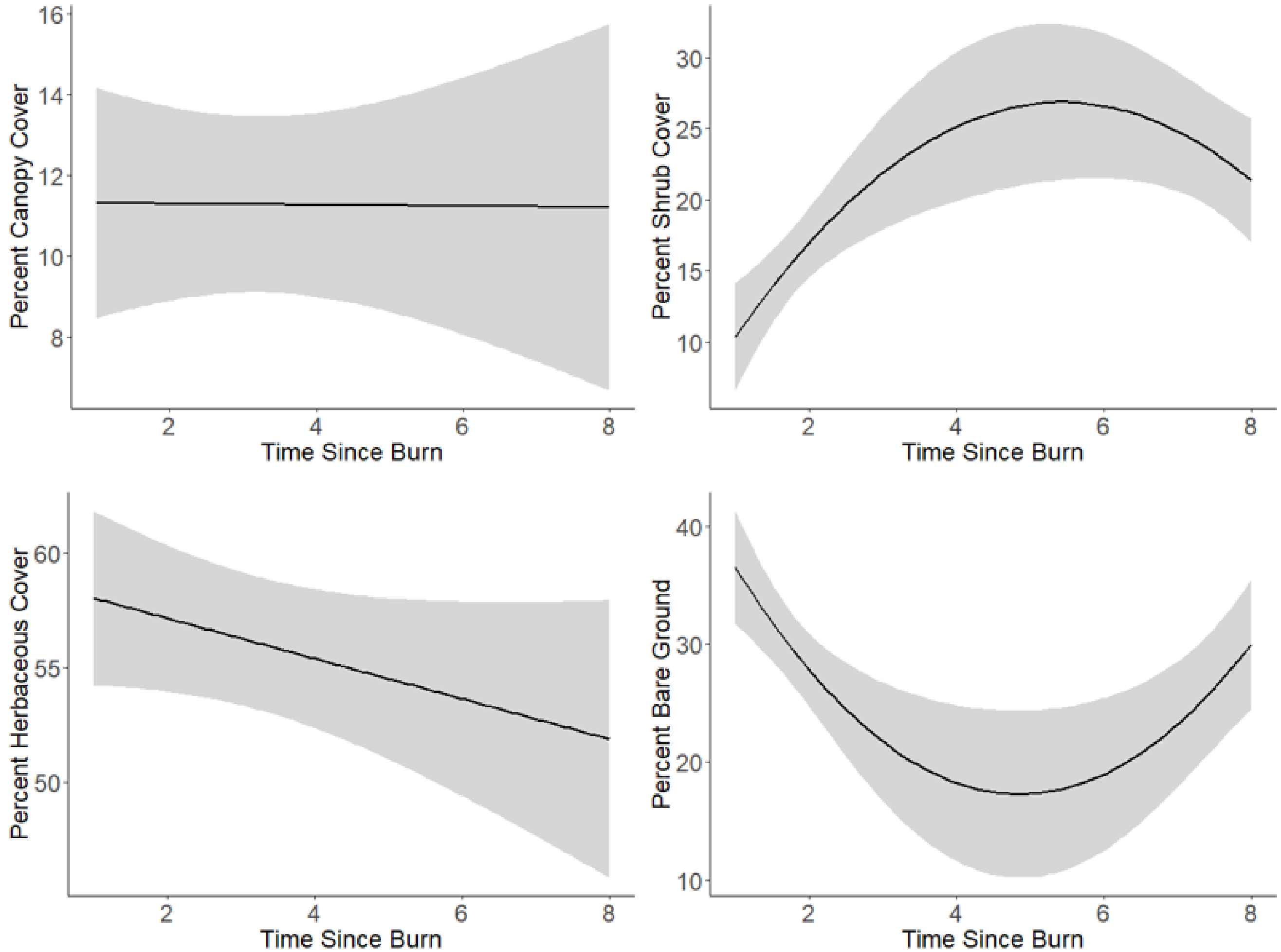

Figure 17. Predicted site-scale vegetation responses to the number of years post prescribed burn or wildfire at Wichita Mountains Wildlife Refuge and adjacent Fort Sill in Oklahoma. Year 8 includes all vegetation survey locations with no recent fire history (i.e., ≤7 years prior to our study) or no known fire history. Also see Appendix G.

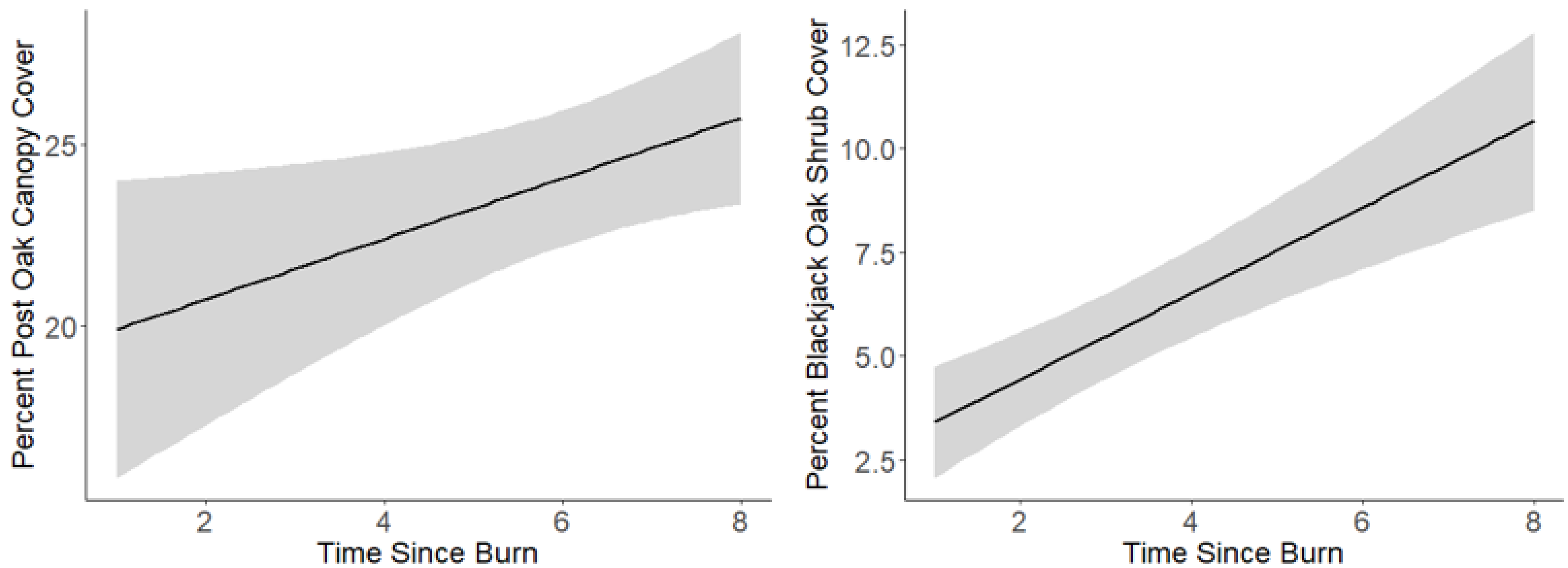

Figure 18. Predicted species-specific site-scale vegetation responses to the number of years post prescribed burn or wildfire at Wichita Mountains Wildlife Refuge and adjacent Fort Sill in Oklahoma. Year 8 includes all vegetation survey locations with no recent fire history (i.e., ≤7 years prior to our study) or no known fire history. Also see Appendix G.

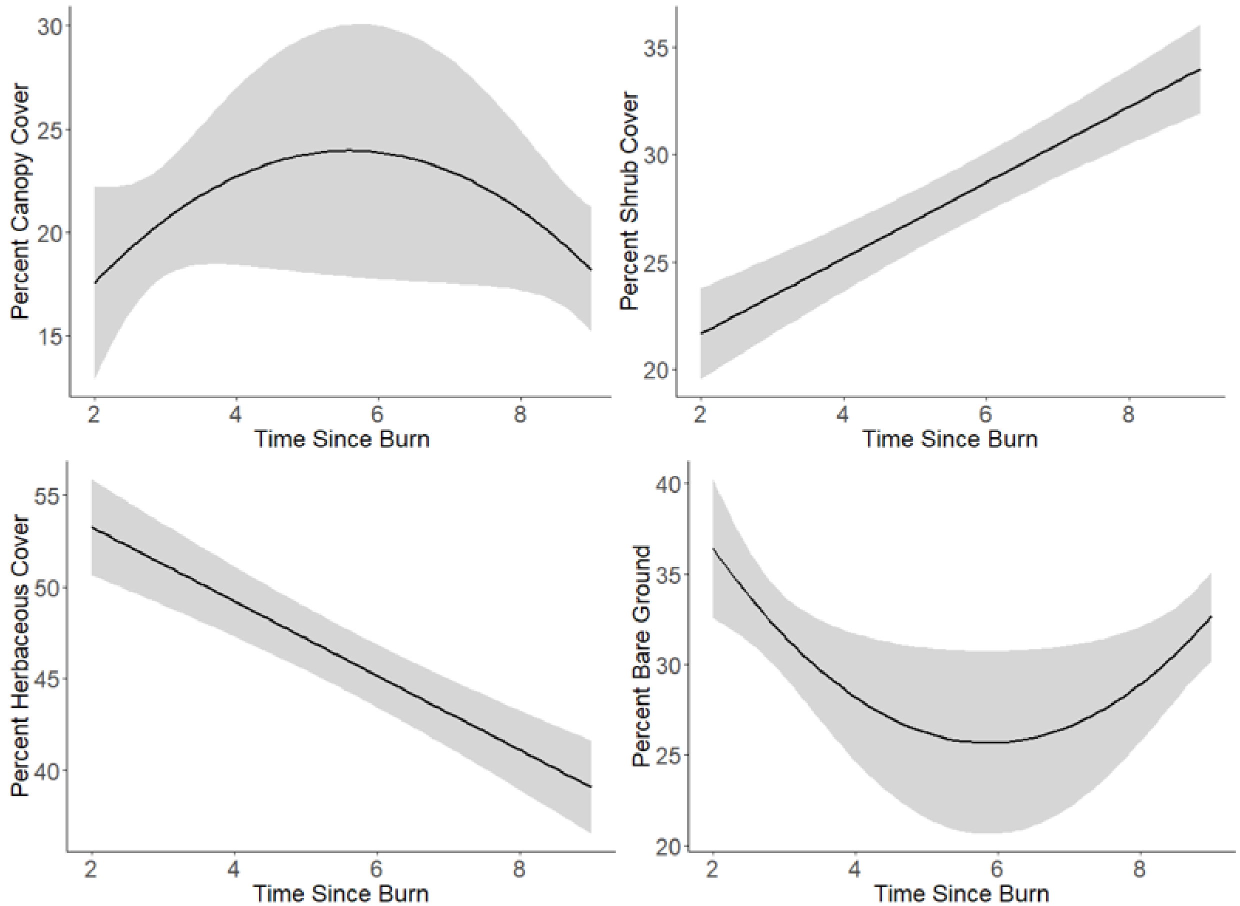

Figure 19. Predicted vegetation responses for data collected at the scale of Black-capped Vireo (*Vireo atricapilla*) territories in response to the number of years post prescribed burn or wildfire at Wichita Mountains Wildlife Refuge and adjacent Fort Sill in Oklahoma. Year 8 includes all vegetation survey locations with no recent fire history (i.e., $\leq$7 years prior to our study) or no known fire history. Also see Appendix G.

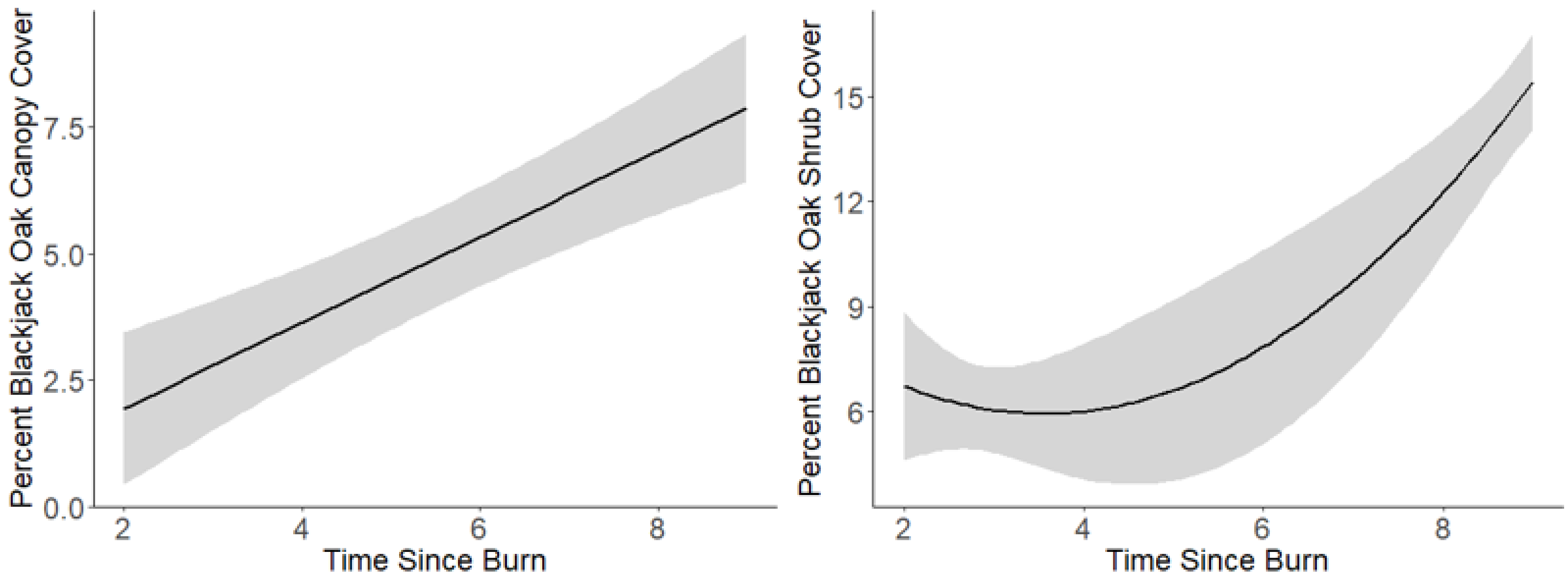

Figure 20. Predicted species-specific vegetation responses for data collected at the scale of Black-capped Vireo (*Vireo atricapilla*) territories in response to the number of years post prescribed burn or wildfire at Wichita Mountains Wildlife Refuge and adjacent Fort Sill in Oklahoma. Year 8 includes all vegetation survey locations with no recent fire history (i.e., ≤7 years prior to our study) or no known fire history. Also see Appendix G.

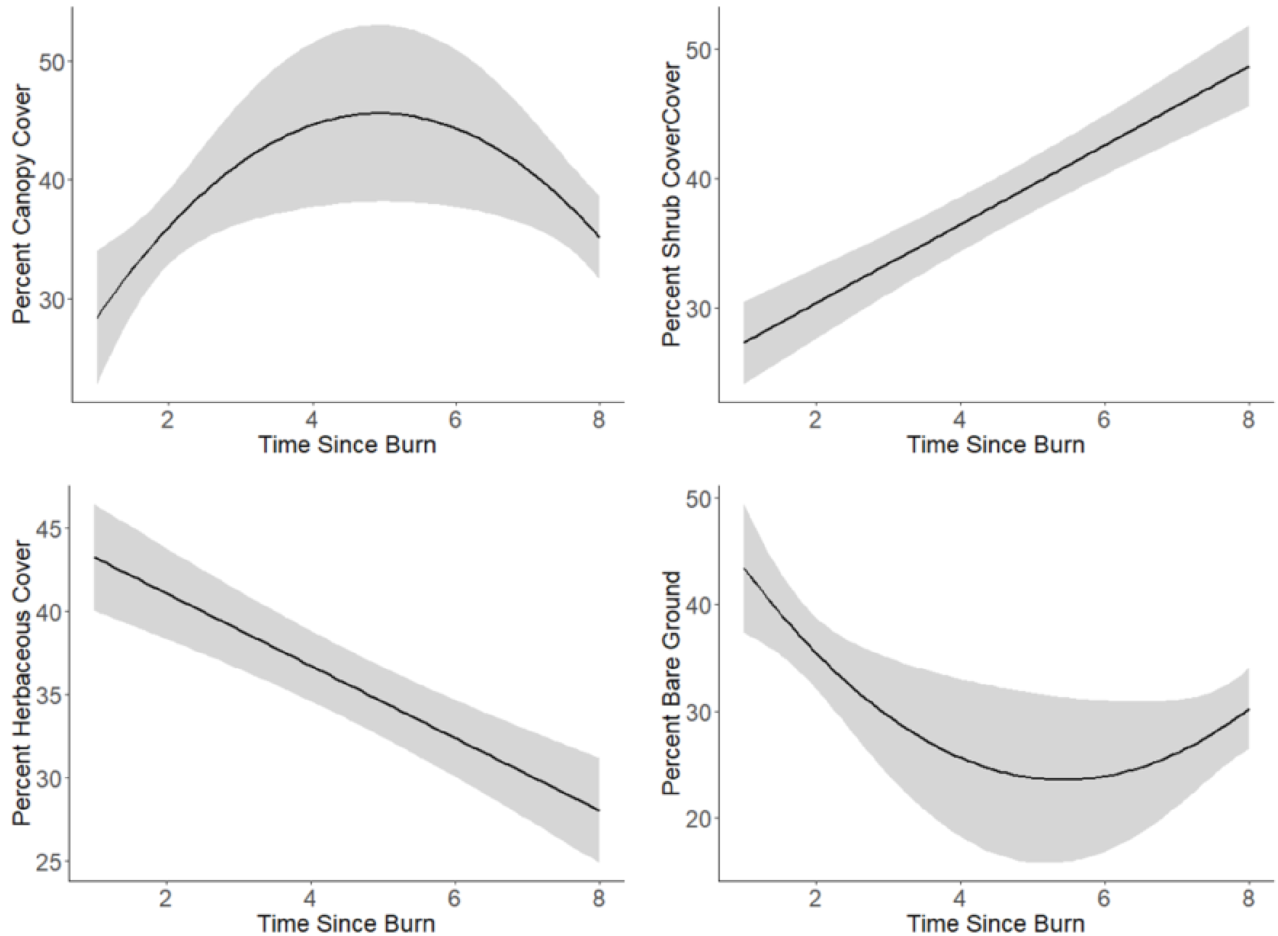

Figure 21. Predicted vegetation responses for data collected at the scale of Black-capped Vireo (*Vireo atricapilla*) nests in response to the number of years post prescribed burn or wildfire at Wichita Mountains Wildlife Refuge and adjacent Fort Sill in Oklahoma. Year 8 includes all vegetation survey locations with no recent fire history (i.e., ≤7 years prior to our study) or no known fire history.

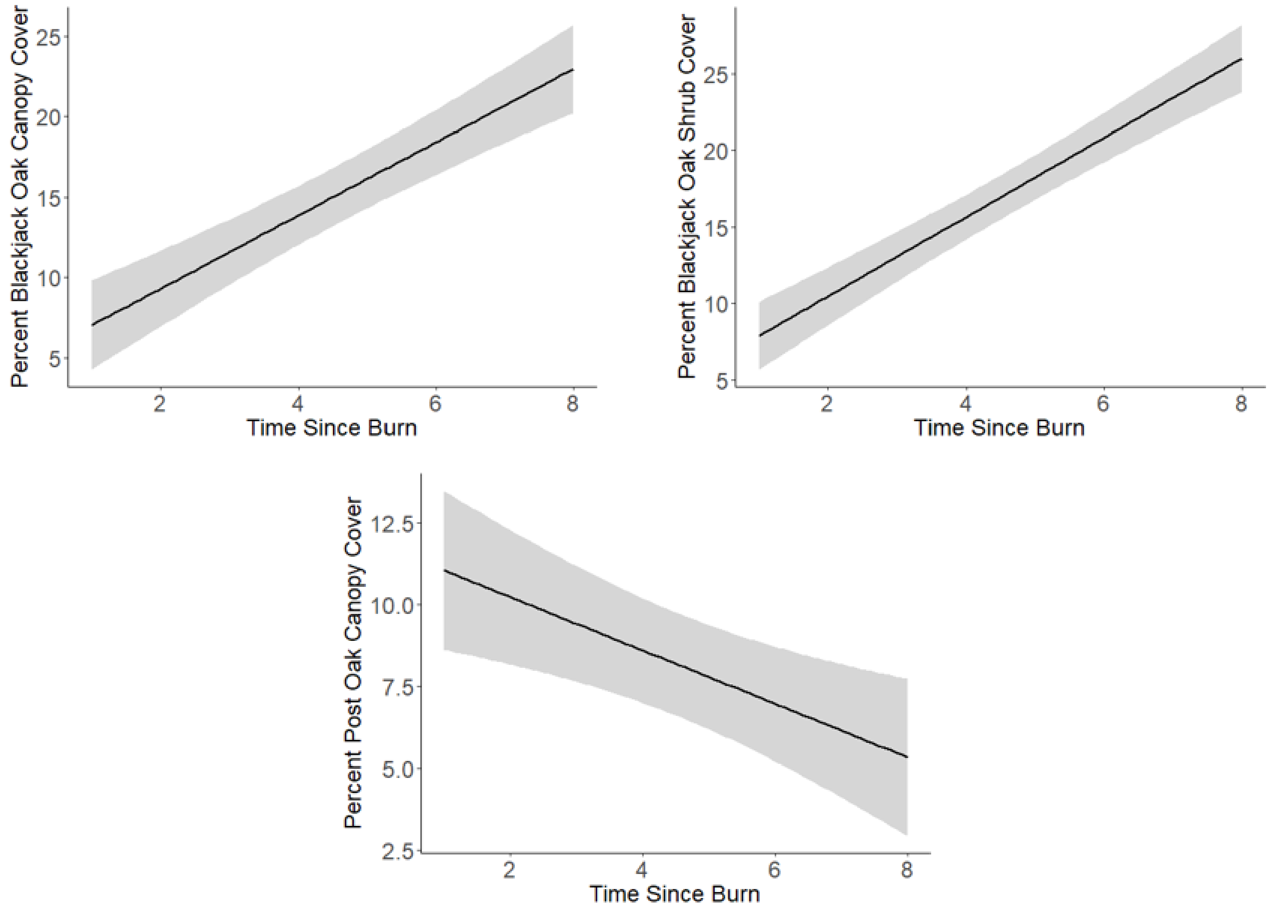

Figure 22. Predicted species-specific vegetation responses for data collected at the scale of Black-capped Vireo (*Vireo atricapilla*) nests in response to the number of years post prescribed burn or wildfire at Wichita Mountains Wildlife Refuge and adjacent Fort Sill in Oklahoma. Year 8 includes all vegetation survey locations with no recent fire history (i.e., ≤7 years prior to our study) or no known fire history. Also see Appendix G.

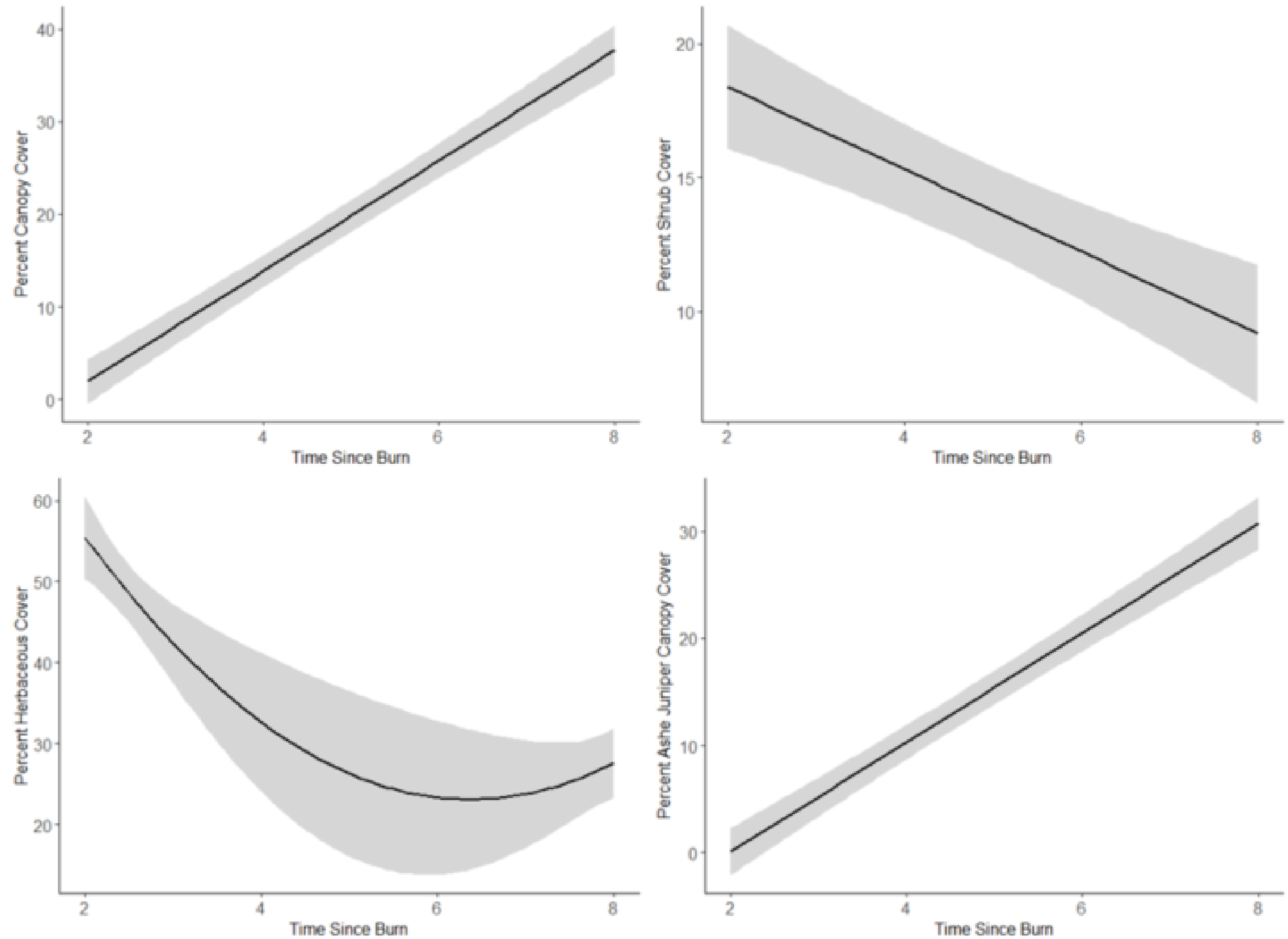

Figure 23. Predicted site-scale vegetation responses to the number of years post prescribed burn or wildfire at Possum Kingdom State Park in Texas. Year 8 includes all vegetation survey locations with no recent fire history (i.e., ≤7 years prior to our study) or no known fire history. Also see Appendix G.

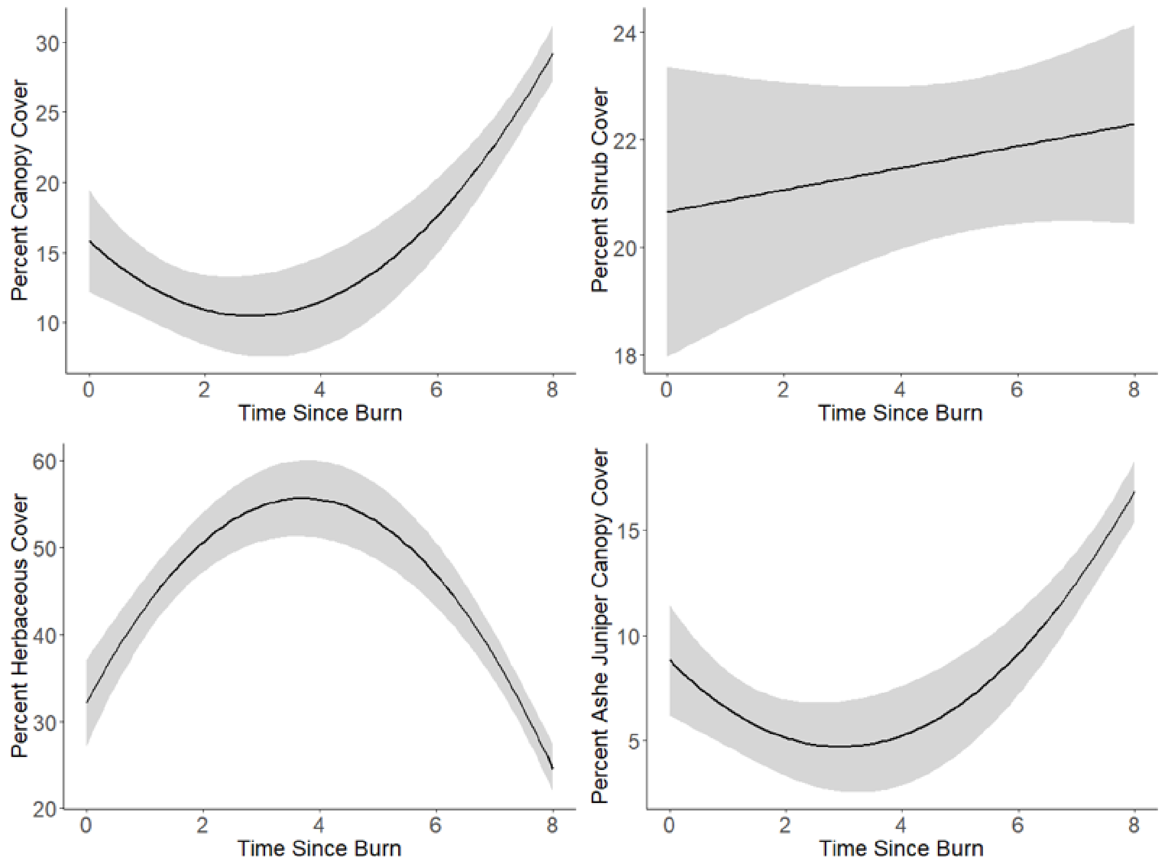

Figure 24. Predicted site-scale vegetation responses to the number of years post prescribed burn or wildfire at Balcones Canyonlands National Wildlife Refuge and adjacent private properties in Texas. Year 8 includes all vegetation survey locations with no recent fire history (i.e., ≤7 years prior to our study) or no known fire history. Also see Appendix G.

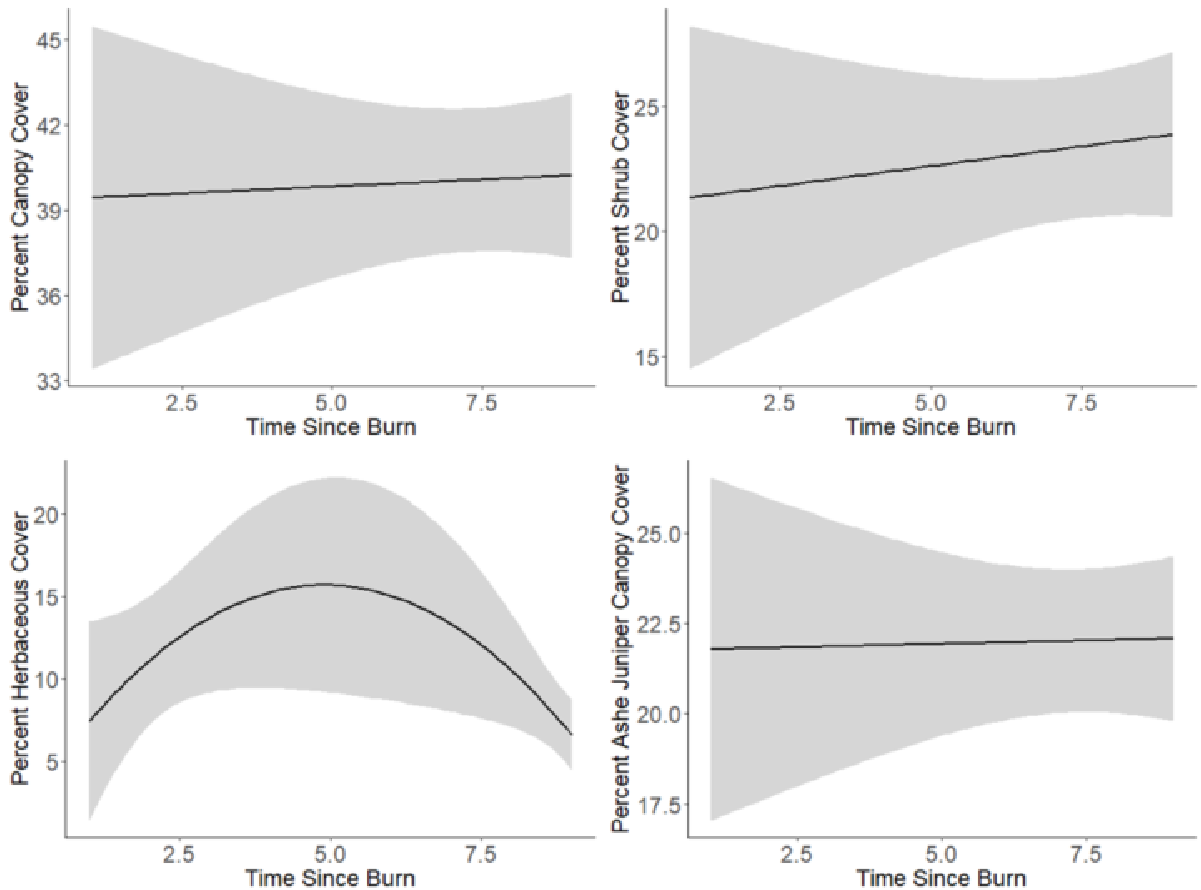

Figure 25. Predicted vegetation responses for data collected at the scale of Golden-cheeked Warbler (*Setophaga chrysoparia*) territories in response to the number of years post prescribed burn or wildfire at Balcones Canyonlands National Wildlife Refuge and adjacent private properties in Texas. Year 8 includes all vegetation survey locations with no recent fire history (i.e., ≤7 years prior to our study) or no known fire history. Also see Appendix G.

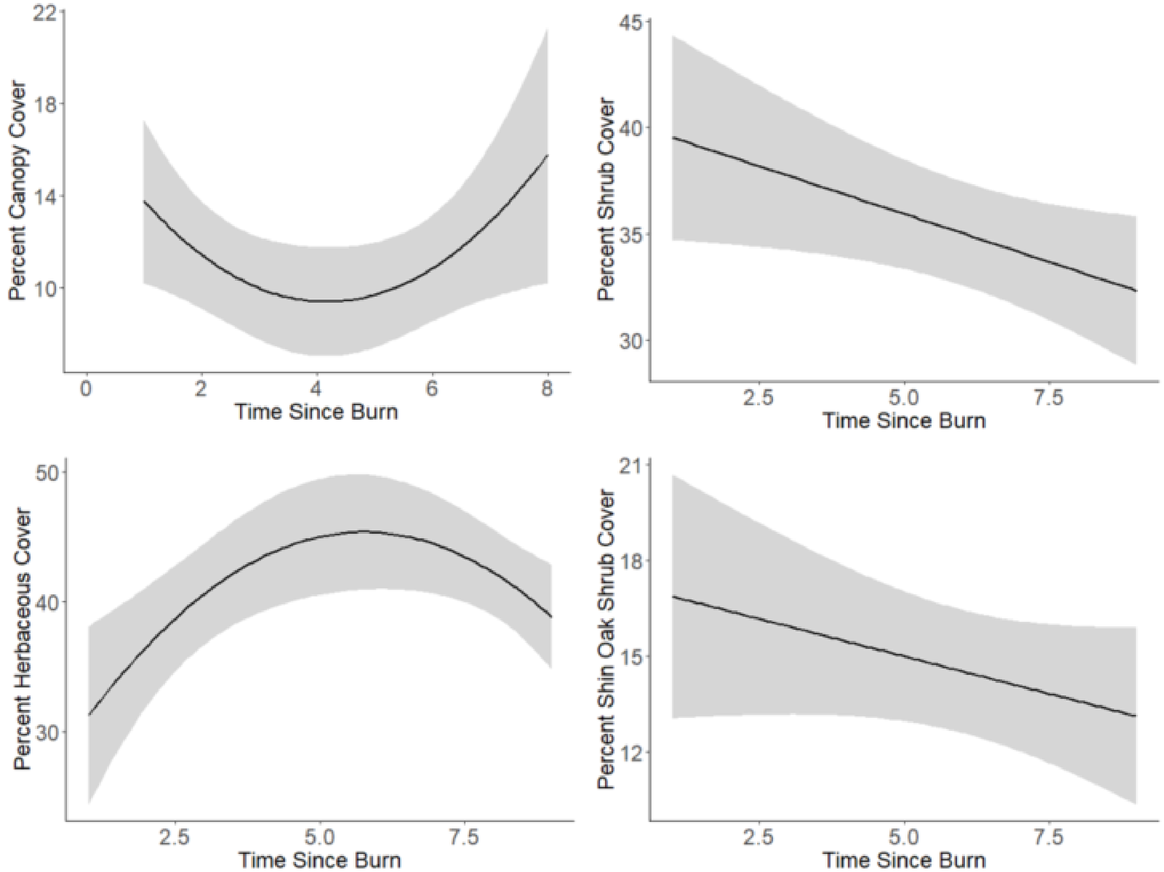

Figure 26. Predicted vegetation responses for data collected at the scale of Black-capped Vireo (*Vireo atricapilla*) territories in response to the number of years post prescribed burn or wildfire at Balcones Canyonlands National Wildlife Refuge and adjacent private properties in Texas. Year 8 includes all vegetation survey locations with no recent fire history (i.e., $\leq$7 years prior to our study) or no known fire history. Also see Appendix G.

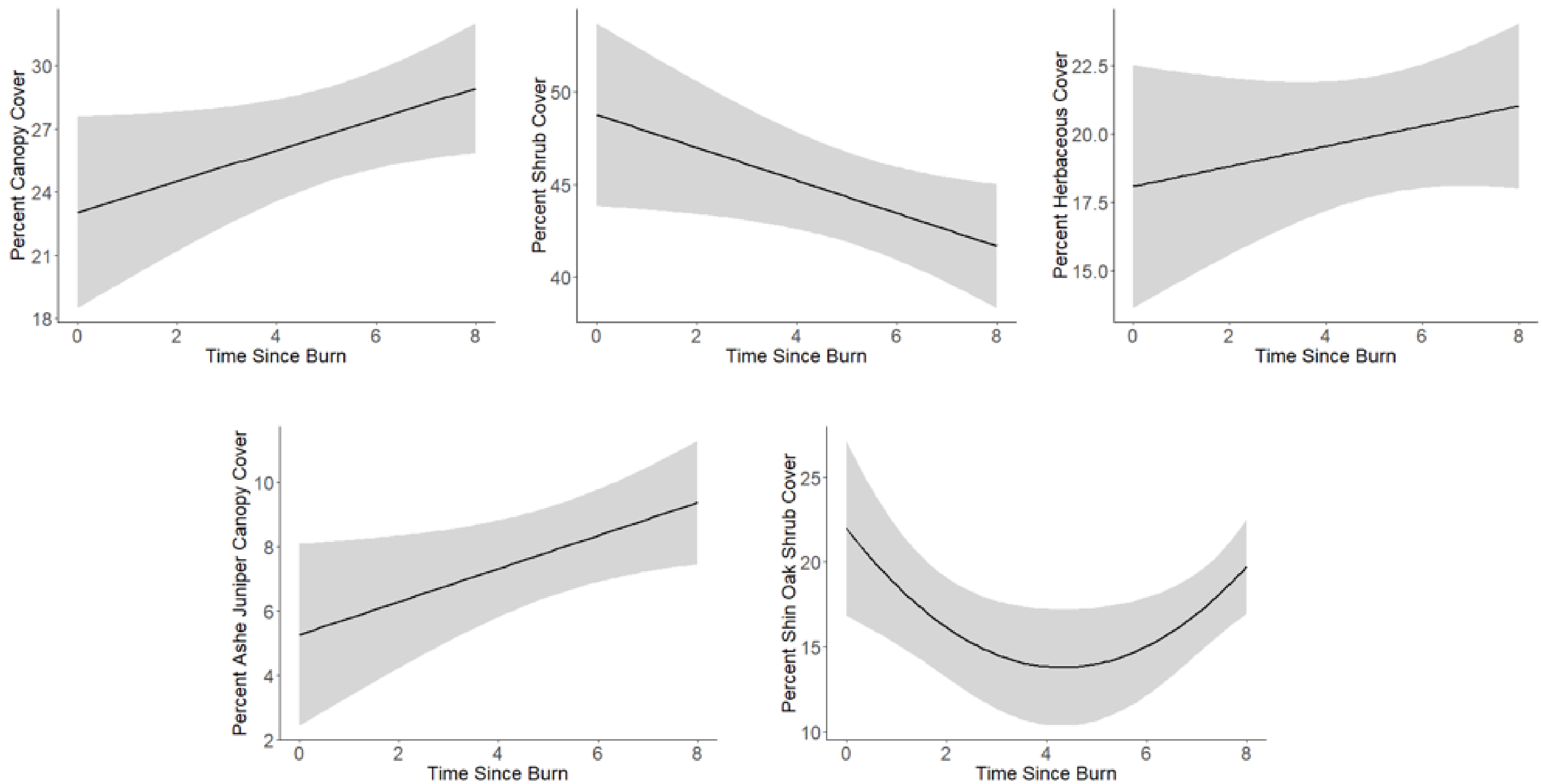

Figure 27. Predicted vegetation responses for data collected at the scale of Black-capped Vireo (*Vireo atricapilla*) nests in response to the number of years post prescribed burn or wildfire at Balcones Canyonlands National Wildlife Refuge and adjacent private properties in Texas. Year 8 includes all vegetation survey locations with no recent fire history (i.e., ≤7 years prior to our study) or no known fire history. Also see Appendix G.

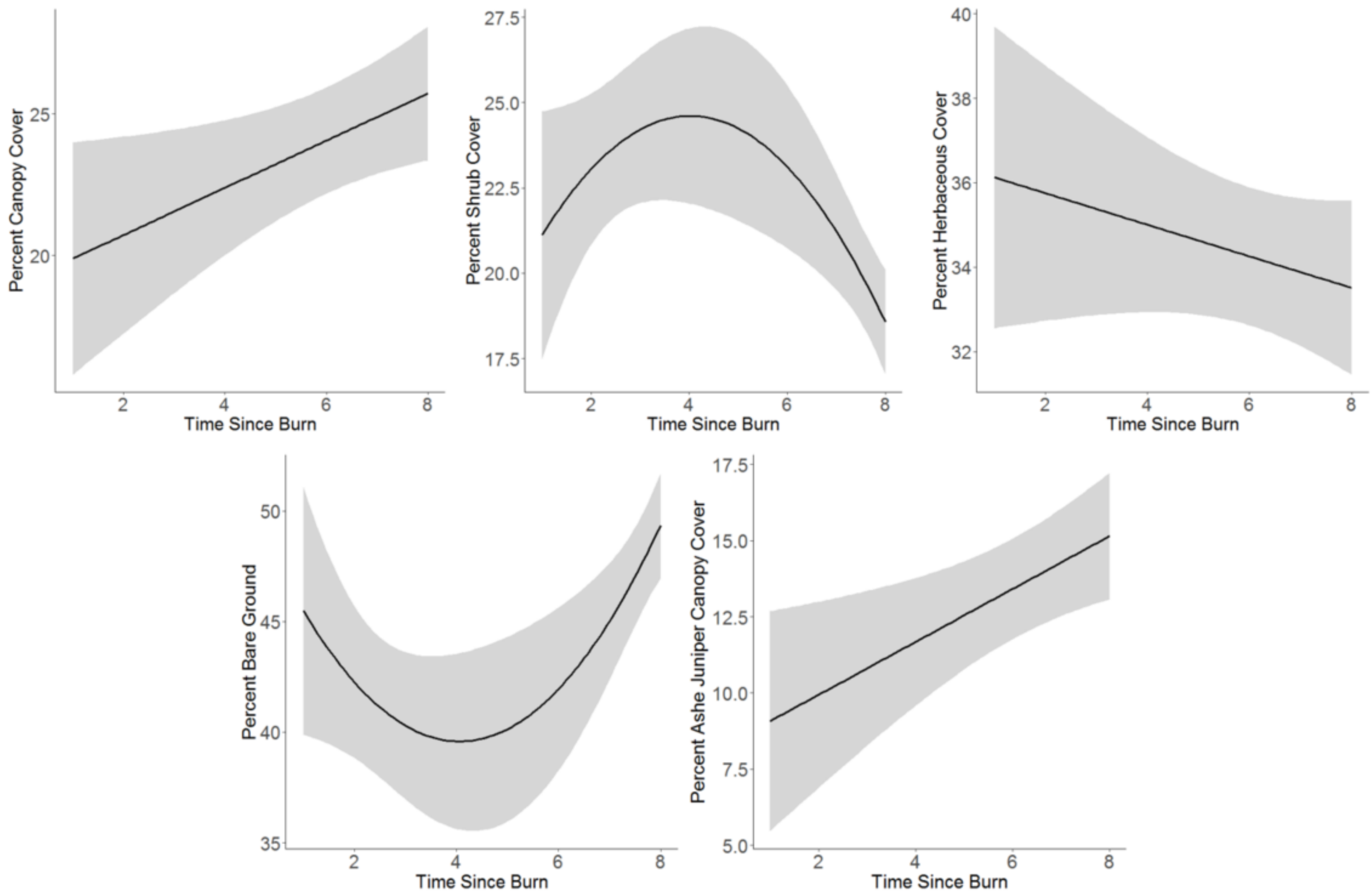

Figure 28. Predicted site-scale vegetation responses to fire frequency at Kerr Wildlife Management Area in Texas. Year 8 includes all vegetation survey locations with no recent fire history (i.e., $\leq$7 years prior to our study) or no known fire history. Also see Appendix G.

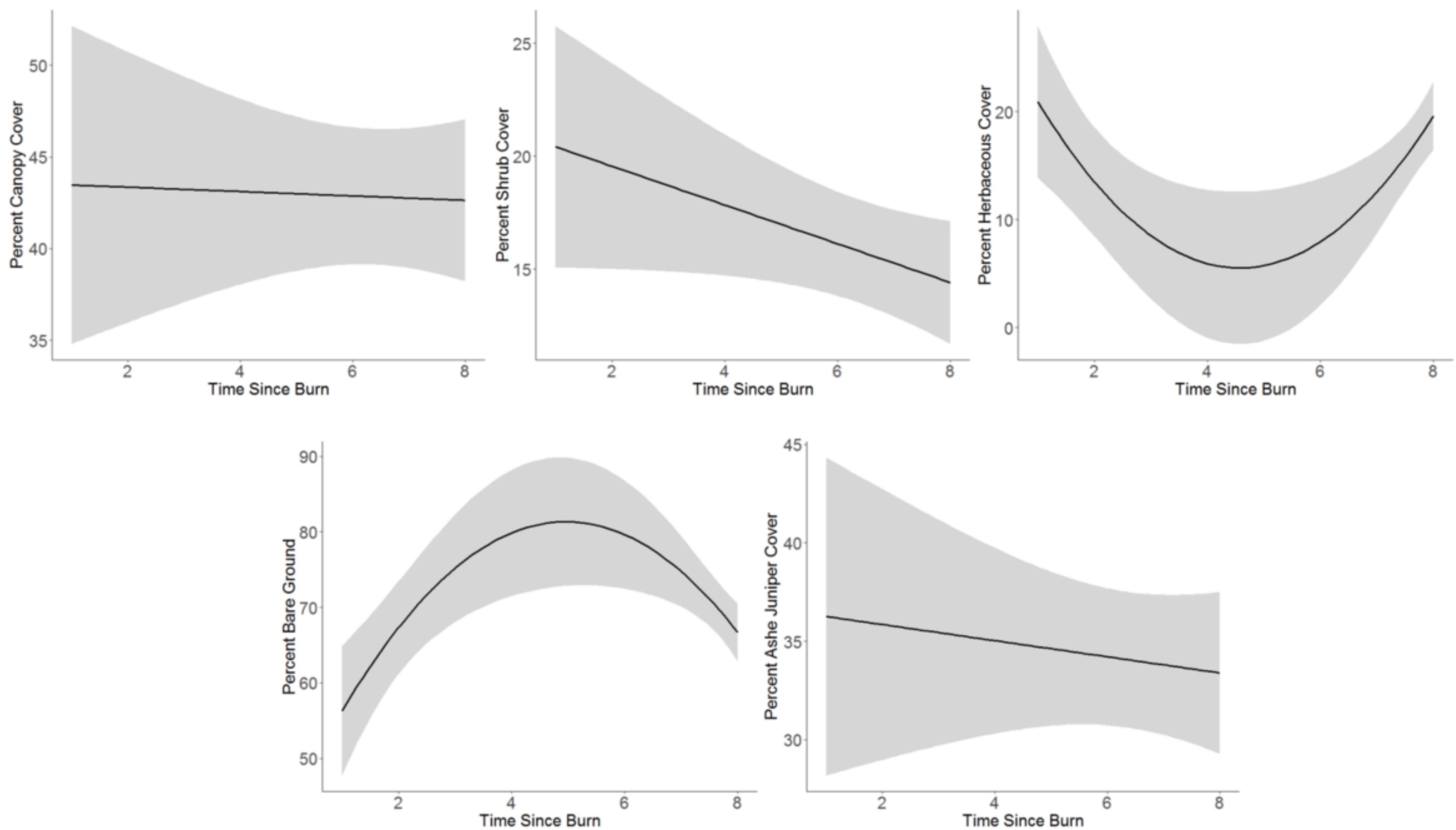

Figure 29. Predicted vegetation responses for data collected at the scale of Golden-cheeked Warbler (*Setophaga chrysoparia*) territories in response to the number of years post prescribed burn or wildfire at Kerr Wildlife Management Area in Texas. Year 8 includes all vegetation survey locations with no recent fire history (i.e., ≤7 years prior to our study) or no known fire history. Also see Appendix G.

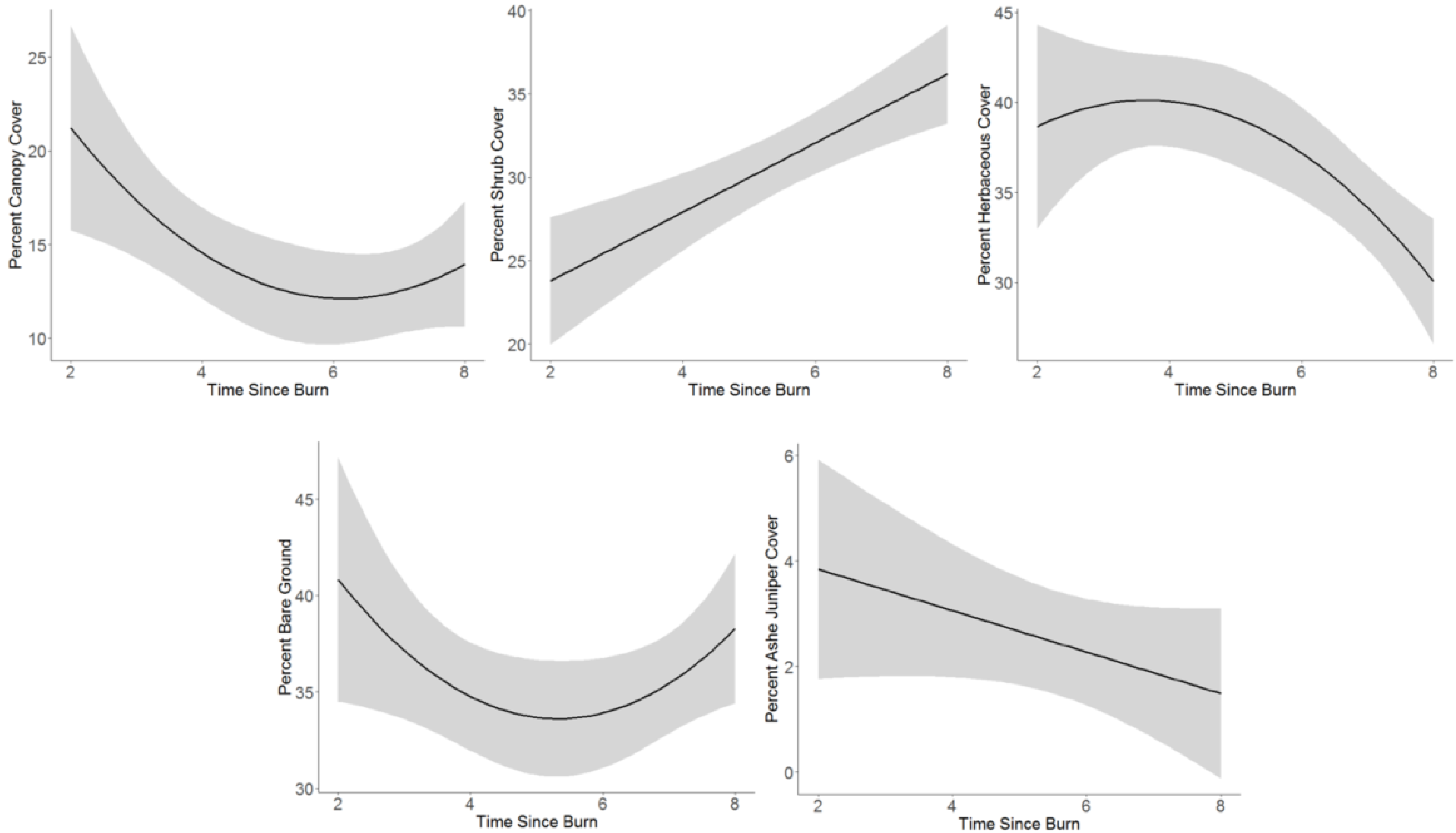

Figure 30. Predicted vegetation responses for data collected at the scale of Black-capped Vireo (*Vireo atricapilla*) territories in response to the number of years post prescribed burn or wildfire at Kerr Wildlife Management Area in Texas. Year 8 includes all vegetation survey locations with no recent fire history (i.e., $\leq$7 years prior to our study) or no known fire history. Also see Appendix G.

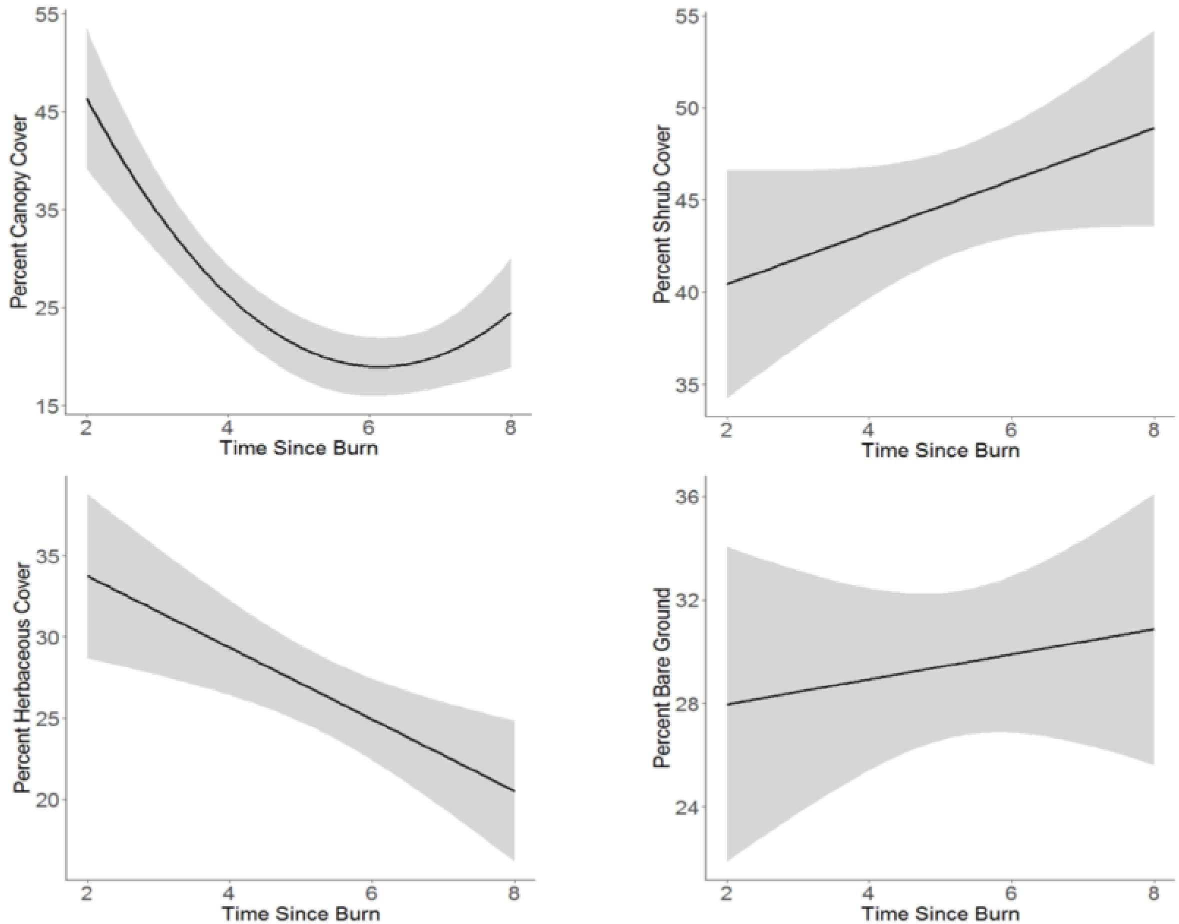

Figure 31. Predicted vegetation responses for data collected at the scale of Black-capped Vireo (*Vireo atricapilla*) nests in response to the number of years post prescribed burn or wildfire at Kerr Wildlife Management Area in Texas. Year 8 includes all vegetation survey locations with no recent fire history (i.e., $\leq$7 years prior to our study) or no known fire history. Also see Appendix G.

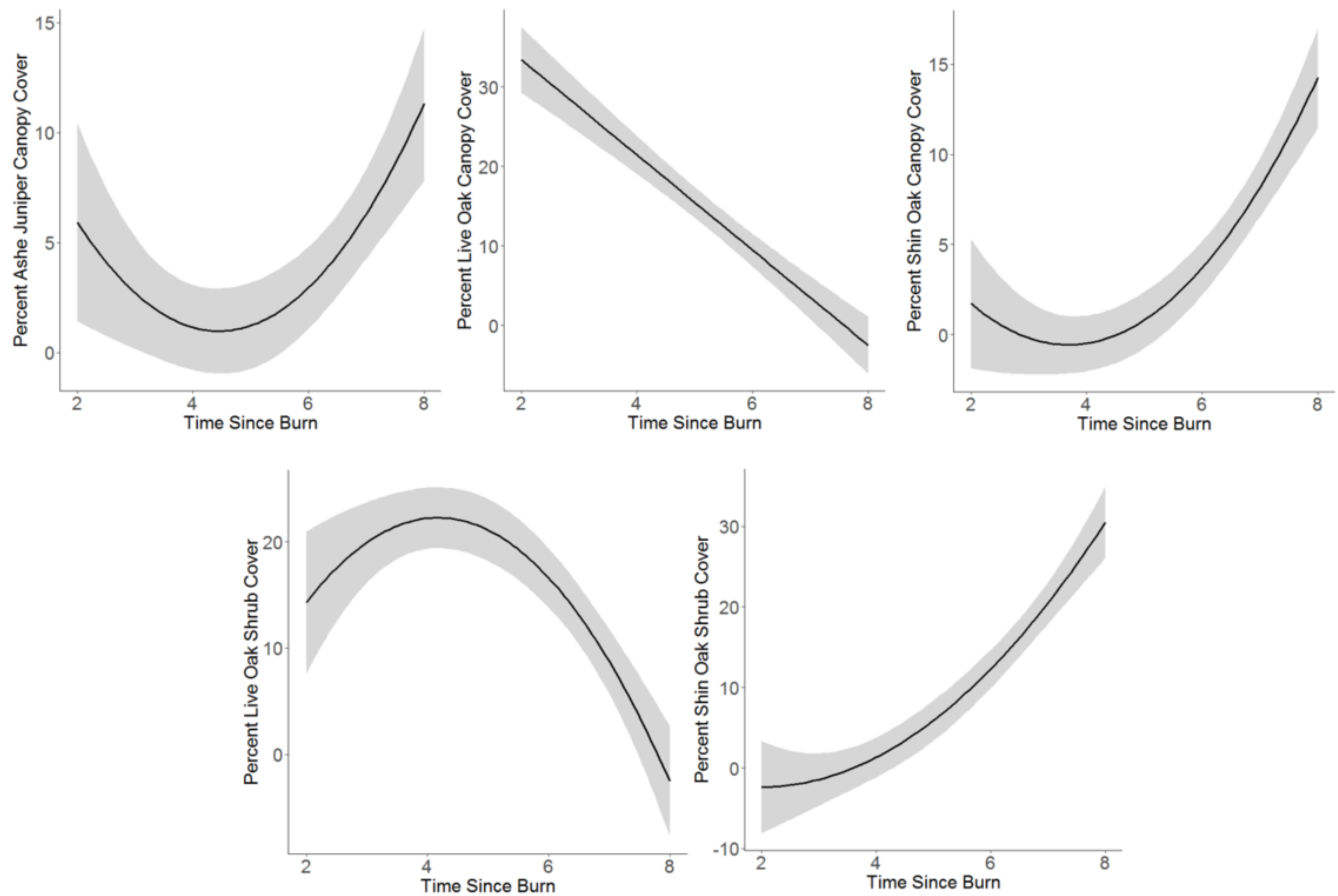

Figure 32. Predicted vegetation responses for data collected at the scale of Black-capped Vireo (*Vireo atricapilla*) nests in response to the number of years post prescribed burn or wildfire at Kerr Wildlife Management Area in Texas. Year 8 includes all vegetation survey locations with no recent fire history (i.e., ≤7 years prior to our study) or no known fire history. Also see Appendix G.

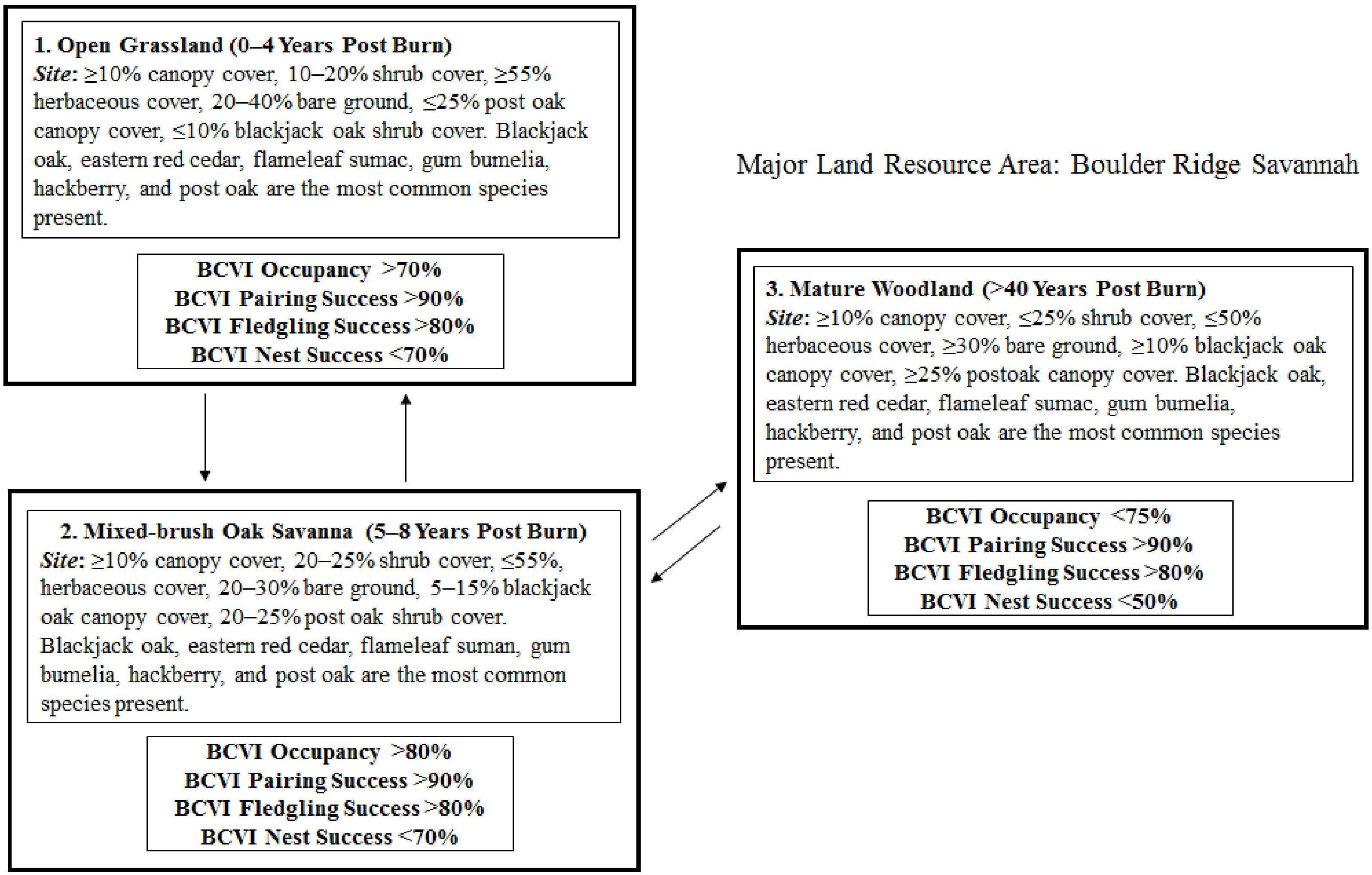

Figure 33. Hypothesized state and transition model for black-capped vireos (*Vireo atricapilla*) in the Boulder Ridge Savannah Major Land Resource Area based on data collected at Wichita Mountains Wildlife Refuge and adjacent Fort Sill in Oklahoma.

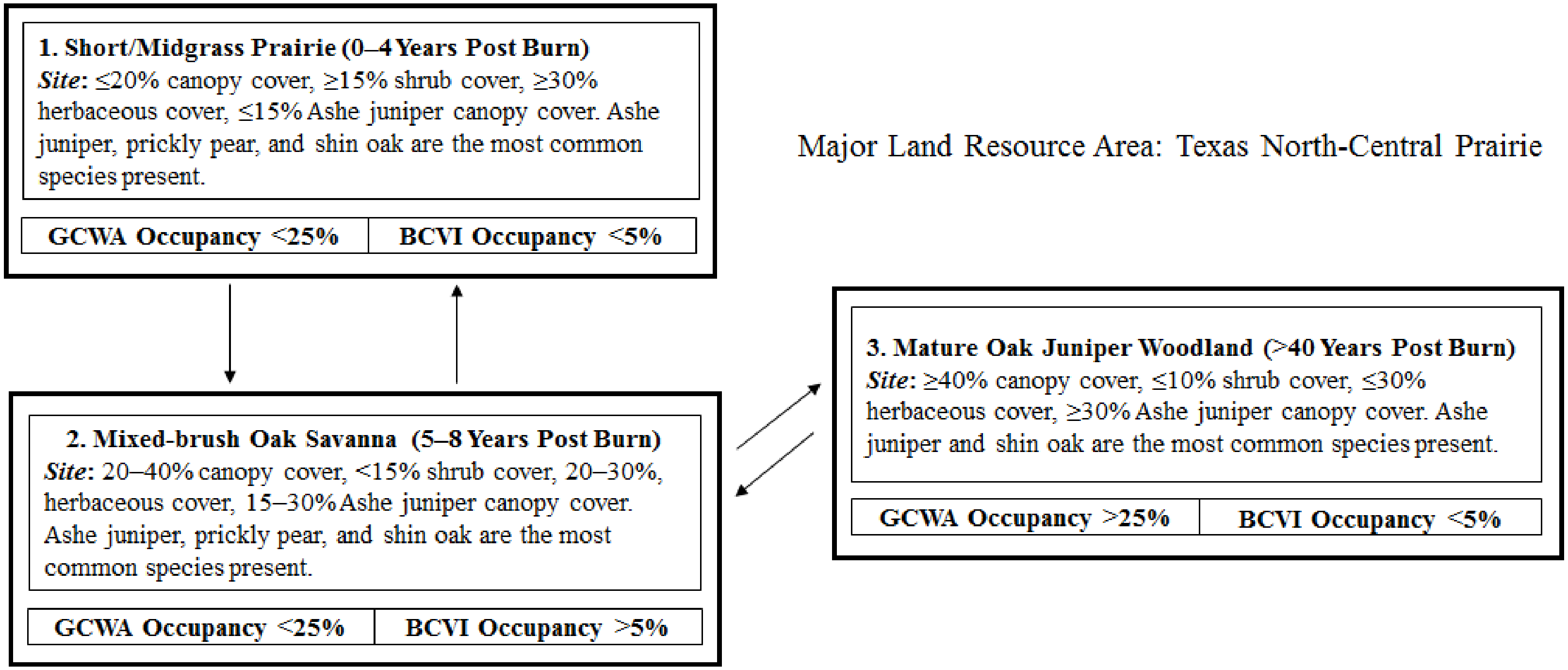

Figure 34. Hypothesized state and transition model for golden-cheeked warblers (*Setophaga chrysoparia*) and black-capped vireos (*Vireo atricapilla*) in the Texas North-Central Prairie Major Land Resource Area based on data collected at Possum Kingdom State Park in Texas.

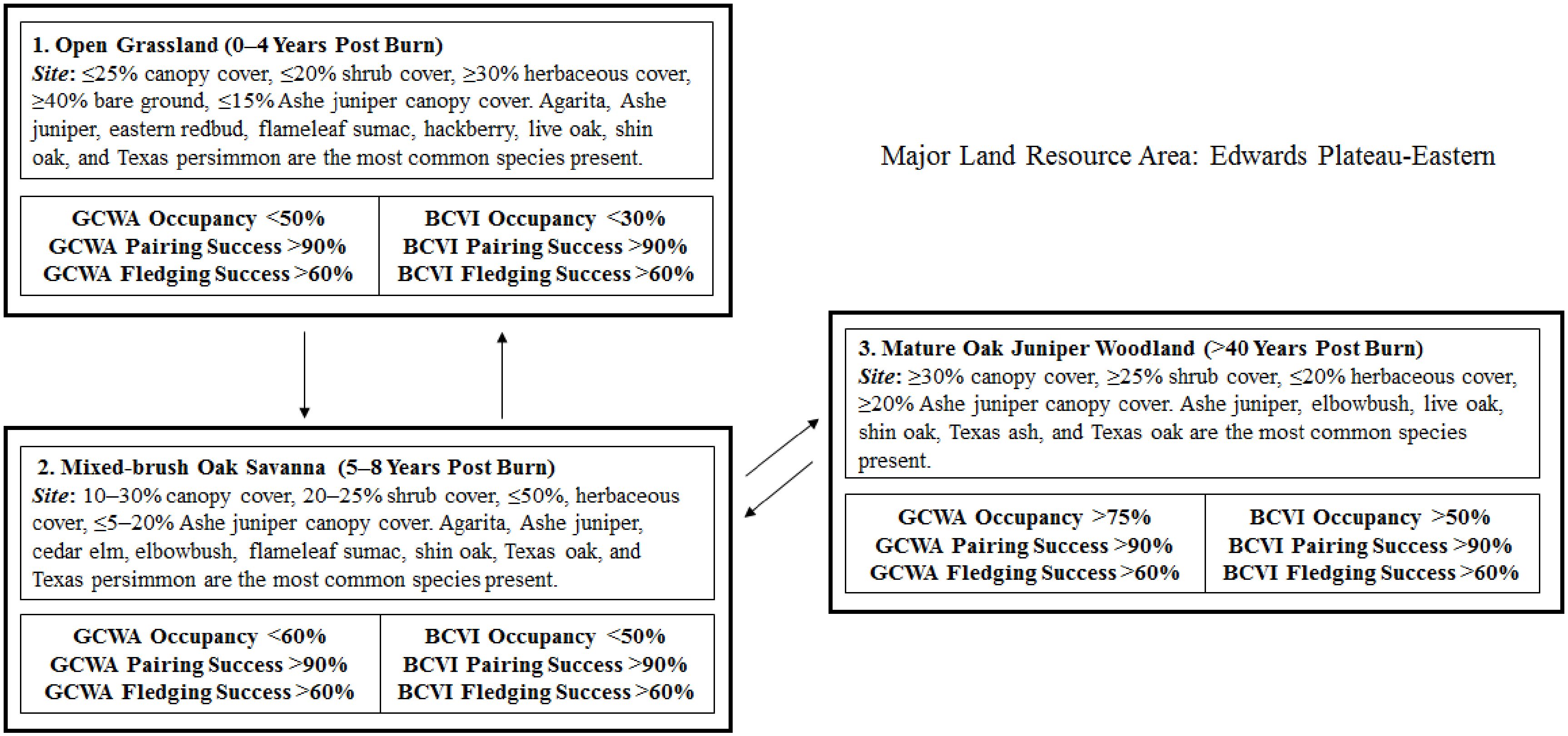

Figure 35. Hypothesized state and transition model for golden-cheeked warblers (*Setophaga chrysoparia*) and black-capped vireos (*Vireo atricapilla*) in the Edwards Plateau-Eastern Major Land Resource Area based on data collected at Balcones Canyonlands National Wildlife Refuge and adjacent private lands in Texas.

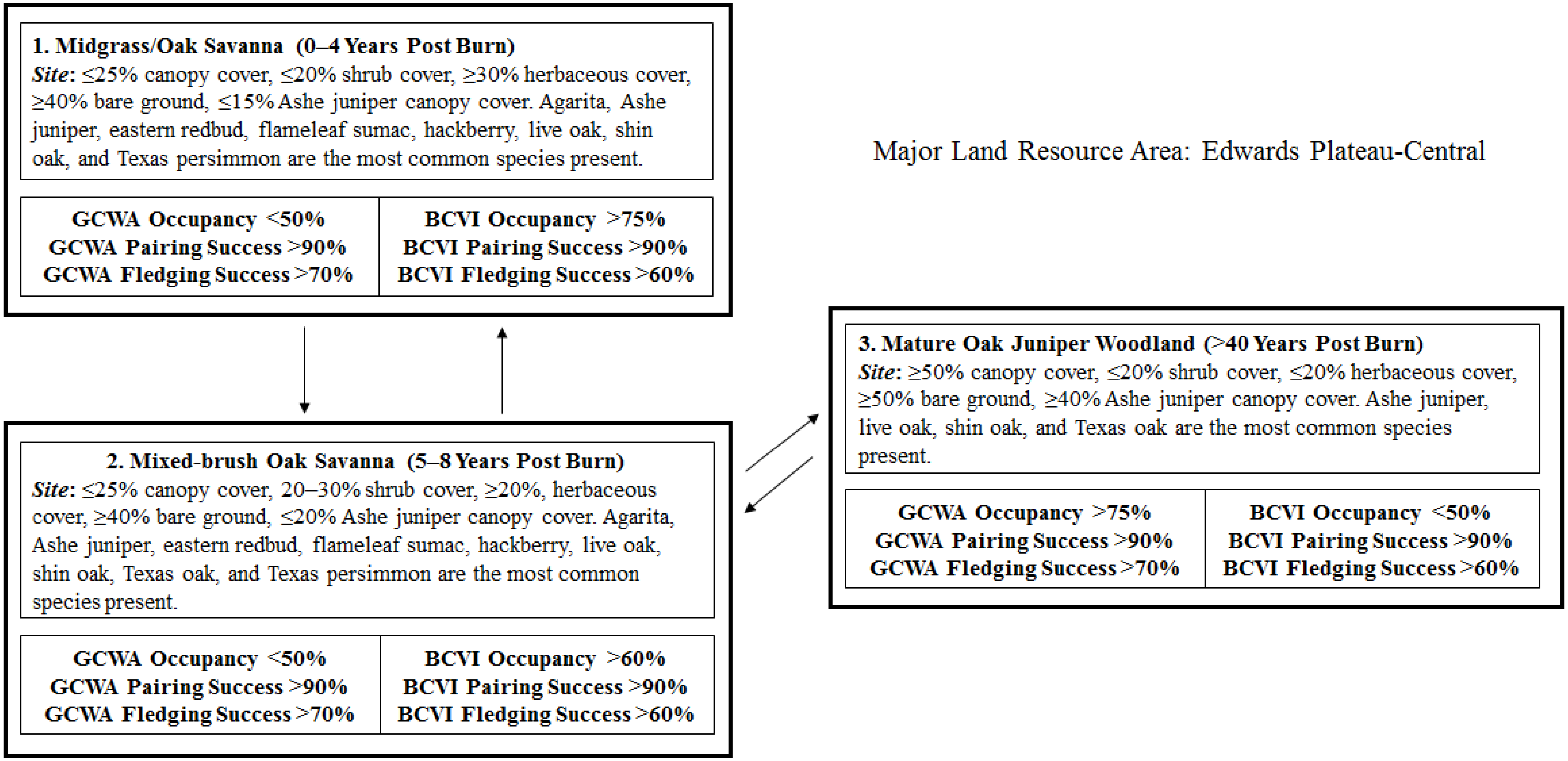

Figure 36. Hypothesized state and transition model for golden-cheeked warblers (*Setophaga chrysoparia*) and black-capped vireos (*Vireo atricapilla*) in the Edwards Plateau-Central Major Land Resource Area based on data collected at Kerr Wildlife Management Area in Texas.

DISCUSSION

Previous research suggests that ecosite is a good predictor of avian density and reproductive success, particularly when environmental conditions are poor (e.g., drought; Marshall et al. 2013, Long 2014, Long et al. 2017). However, in the current study, ecosite explained little (<12%) variation in our site-, territory-, and nest-scale datasets. As such, state-and-transition models (STMs) intended to inform management for warblers and vireos may be most effectively developed at the level of multiple ecological sites. Greater understanding of local avian-habitat relationships and incorporation of predator-prey dynamics into landscape-scale STMs could help improve predictability of site-specific warbler and vireo responses to disturbance. Likewise, data on cowbird parasitism could supplement STMs for longer-term management of vireos and other avian species that are negatively influenced by brood parasites.

The detection probabilities we calculated using our data set were the same or higher for both the warbler and vireo as reported elsewhere in their range (e.g., Farrell et al. 2013) and we were able to identify clear relationships between point-specific vegetation characteristics and the predicted probability of warbler and vireo occupancy. However, we were not able to define clear relationships between warbler and vireo density and our vegetative responses given the scale at which we measured this response. In addition, high rates of pairing and fledging success (which corresponded with site-specific estimates reported from across both species' breeding ranges; Wilkins et al. 2006, Groce et al. 2010) resulted in weak predictive relationships between our territory-scale vegetation metrics and avian pairing and fledging success. As such, we excluded warbler and vireo density from our STMs, and we used site-scale vegetation metrics to describe the vegetative communities and expected warbler and vireo pairing and fledging success across vegetative states. While more detailed information on avian-habitat relationships may be necessary for site-specific management, more general associations as presented in our STMs may be sufficient for landscape-scale conservation planning.

As expected given the known natural history of the warbler and vireo, our multi-species, multi-response STM approach showed that there is a general trend of decreasing probability of vireo occupancy and nesting success as succession proceeds post-burn and a general increasing probability of warbler occupancy and nesting success post-burn. As a tool for warbler and vireo conservation, STMs could help predict the long-term goals for management treatments (e.g., fire frequency), but also provide guidance on the plant species that could be favored during site treatments. For example, at Kerr (Fig. 36), if environmental conditions following a prescribed fire are suboptimal for growth of plants used by vireos (e.g., Ashe juniper, shin oak, Texas persimmon), then steps could be taken (e.g., planting, spot watering, thinning of competing plants) to enhance these plant species. Additionally, if a goal of management at Kerr is also enhancement of conditions for warblers, the STM shows that Ashe juniper and oak species should be considered as succession proceeds (Fig. 36).

Somewhat counter to our initial expectations, however, were STM results for Balcones (Fig. 35). Though vegetative conditions sufficient for vireo occupancy are present within 8 years post burn, examination of individual metrics indicate that the predicted probability of vireo occupancy did not exceed >50% until >8 years post wildfire or prescribed burn. Based on quantification of individual vegetation metrics common to vireo habitat in this region, this time period is necessary for early successional vegetation to develop within open savanna conditions sufficiently for the predicted probability of vireo occupancy to improve. Concurrently, warbler occupancy improved with time as larger and denser patches of woodland developed within the (now former) savanna, and by 40 years post burn a shift had occurred in the species composition of the understory to one providing more shrub (primarily oak species) structure. Such relationships and hypotheses represented by our STMs should be tested when more data becomes available for warblers and vireos within this Major Land Resource Area.

Science Delivery

Co-Principal Investigator Heather Mathewson presented interim results to staff members of the Balcones Canyonlands National Wildlife Refuge and Wichita Mountains Wildlife Refuge. Collaborator Ashley Long and her co-authors published two peer-reviewed publications using data collected for this project, including a description of black-capped vireo habitat in north Texas and the first documented observation of a male golden-cheeked warbler in Oklahoma. Two graduate students (Ronnisha Holden and Marisa Martinez) presented data collected for this project at annual Texas Chapter of the Wildlife Society meetings (one presentation in 2013 and two presentations in 2014). These students also incorporated data collected for this project into their M.S. theses and subsequent peer-reviewed manuscripts. Funding for this project supported research experience for 25 undergraduate students and early career wildlife professionals. We intend to prepare and submit at least two more papers for peer-review, including a project synthesis and a range-wide evaluation of black-capped vireo nest survival in relation to environmental conditions, and we intend to prepare an extension publication for landowners and land managers that explains how they can use an STM approach to manage wildlife on their property.

CONCLUSIONS AND IMPLICATIONS FOR MANAGEMENT

Wildlife biologists have been slow to further test or adopt state-and-transition models (STMs) as a tool in landscape-scale conservation planning. However, our results demonstrate a multi-species, multi-response approach that land managers could use to minimize the negative effects or enhance the positive effects of disturbance on wildlife populations of conservation concern. As Bestelmeyer (2015) suggested, we found that that STMs intended to assist with wildlife management may be most effectively developed at the level of multiple ecological sites. We acknowledge that extensive data regarding wildlife-habitat relationships necessary to quantify variation in vegetation characteristics are limited for most species. However, as a starting point, expert opinion could be used to develop region-specific STMs, which may guide hypothesis testing and data-driven adaptive management, with data incorporated as it becomes available. Integration of remotely sensed data into STMs may also greatly increase the speed at which STMs could be developed, tested, and refined for landscape-scale conservation planning purposes.

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APPENDIX B: List of Completed/Planned Publications and Products

1. Articles in peer-reviewed journals:
    - Holden, R. S., M. L. Morrison, and H. A. Mathewson. 2017. The influence of temperature on black-capped vireo nest site selection. Southeastern Naturalist: In Press.
    - Long, A. L., D. S. Finn, J. A. Grzybowski, M. L. Morrison, and H. A. Mathewson. 2014. First documented observation of the federally endangered Golden-cheeked warbler (*Setophaga chrysoparia*) in Oklahoma. Bulletin of the Oklahoma Ornithological Society 47:9–13.
    - Long, A. M., H. A. Mathewson, D. H. Robinson, J. A. Grzybowski, and M. L. Morrison. 2015. Black-capped vireo breeding habitat in north-central Texas. Western Birds 46:256–260.
    - Martinez, M. T., M. L. Morrison, A. M. Long, and H. A. Mathewson. Broad-scale habitat use of fledging black-capped vireos. In Review.
    - Additional manuscripts In Prep (see Scientific Delivery)
2. Technical reports: TBD
3. Text books or chapters: NA
4. Graduate thesis
    - Holden, R. S. 2016. The influence of temperature on black-capped vireo nest site selection. Thesis, Texas A&M University, College Station, Texas, USA.
    - Martinez, M. T. 2015. Multi-scale habitat use of fledgling black-capped vireos across two temporal scales. Thesis, Texas A&M University, College Station, Texas, USA.
5. Conference symposium proceedings scientifically recognized and referenced: NA
6. Conference or symposium abstracts:
    - Holden, R. S. February 2014. The influence of temperature on black-capped vireo nest site selection. 50th Annual Meeting of the Texas Chapter of the Wildlife Society. Austin, Texas.
    - Martinez, M. T. February 2013. Multi-scale habitat use of fledgling black-capped vireos across two temporal scales. 49th Annual Meeting of the Texas Chapter of the Wildlife Society. Houston, Texas.
    - Martinez, M. T. February 2014. Multi-scale habitat use of fledgling black-capped vireos across two temporal scales. 50th Annual Meeting of the Texas Chapter of the Wildlife Society. Austin, Texas.
7. Posters: NA
8. Workshop materials and outcome reports: NA
9. Field demonstrations/tour summaries: NA
10. Website development: NA
11. Presentations/webinars/other outreach/science delivery materials: NA

APPENDIX C: Metadata

We store and archive data on several secure drives at our offices in College Station. We will also submit our data to the United States Forest Service Research Data Archive (http://www.fs.usda.gov/rds/archive).

APPENDIX D: Comparisons of Vegetation Across Ecosites

Table D6. Means and standard deviations in parentheses for vegetation variables across ecosites at the Wichita Mountains Wildlife Refuge and adjacent Fort Sill Military Reservation in Oklahoma. Given small samples sizes for the Clay Loam and Loamy Bottomland ecosites, we did not compare means statistically across groups.

Scale	Vegetation Variables with >30 Observations	Boulder Ridge Savannah	Clay Loam	Loamy Bottomland
Site[1]	Canopy cover	11.0 (17.6)	50.0 (14.1)	—
	Shrub cover	16.8 (17.3)	46.3 (5.3)	—
	Herbaceous cover	56.2 (24.1)	45.0 (7.1)	—
	Bare cover	29.6 (22.0)	21.3 (19.5)	—
	Visual obstruction (0–1 m)	5.1 (9.9)	13.0 (15.6)	—
	Visual obstruction (1–2 m)	1.9 (4.0)	0.0 (0.0)	—
	Blackjack oak shrub cover	5.6 (8.8)	15.0 (21.2)	—
Territory[2]	Canopy cover	19.0 (21.5)	38.4 (28.5)	54.5 (33.7)
	Shrub cover	26.9 (17.4)	39.8 (18.7)	28.8 (11.1)
	Herbaceous cover	46.8 (21.7)	40.7 (20.6)	36.3 (16.1)
	Bare cover	37.8 (19.6)	23.4 (21.4)	50.6 (11.4)
	Visual obstruction (0–1 m)	7.5 (9.8)	12.9 (12.2)	6.0 (4.3)
	Visual obstruction (1–2 m)	4.2 (7.6)	2.5 (2.5)	3.0 (4.8)
	Visual obstruction (2–3 m)	3.4 (7.1)	3.8 (5.9)	0.5 (1.0)
	Blackjack oak shrub cover	9.5 (10.7)	4.0 (3.9)	7.0 (3.5)
	Gum bumelia shrub cover	0.2 (1.5)	1.3 (3.6)	0.0 (0.0)
	Hackberry shrub cover	0.8 (2.4)	2.0 (3.0)	0.0 (0.0)
	Post oak shrub cover	1.5 (4.2)	1.5 (2.7)	2.0 (0.0)
	Eastern red cedar shrub cover	0.9 (2.6)	0.0 (0.0)	4.5 (7.7)
	Blackjack oak canopy cover	4.3 (10.9)	16.7 (19.3)	14.0 (18.9)
	Eastern red cedar canopy cover	4.9 (10.9)	4.2 (8.9)	0.0 (0.0)
Nest[3]	Canopy cover	35.5 (20.8)	19.0 (1.4)	28.7 (15.3)
	Shrub cover	38.1 (20.7)	36.3 (12.4)	41.7 (25.0)
	Herbaceous cover	35.5 (19.4)	40.0 (17.7)	35.0 (41.2)
	Bare cover	33.6 (22.4)	23.8 (5.3)	39.2 (21.0)
	Visual obstruction (0–1 m)	13.8 (14.1)	8.0 (2.8)	10.7 (4.6)
	Visual obstruction (1–2 m)	11.6 (11.0)	3.0 (1.4)	11.3 (7.6)
	Visual obstruction (2–3 m)	9.4 (10.8)	0.0 (0.0)	14.7 (5.0)
	Blackjack oak shrub cover	17.1 (15.1)	8.0 (11.3)	15.3 (1.2)
	Hackberry shrub cover	1.3 (5.3)	4.0 (5.7)	0.0 (0.0)
	Post oak shrub cover	1.5 (4.2)	0.0 (0.0)	7.3 (11.0)
	Eastern red cedar shrub cover	2.0 (4.6)	1.0 (1.4)	2.0 (2.0)
	Blackjack oak canopy cover	15.3 (17.5)	10.0 (14.1)	2.0 (3.5)

Post oak canopy cover	8.1 (14.1)	0.0 (0.0)	22.3 (19.7)
Eastern red cedar canopy cover	8.2 (12.4)	4.0 (5.7)	0.0 (0.0)

[1] Boulder Ridge Savannah n = 263, Clay Loam n = 2, Loamy Bottomland n = 0
[2] Boulder Ridge Savannah n = 840, Clay Loam n = 11, Loamy Bottomland n = 4; Includes only black-capped vireo (*Vireo atricapilla*) territories
[3] Boulder Ridge Savanna n = 298, Clay Loam n = 2, Loamy Bottomland n = 3; Includes only black-capped vireo nests

Table D7. Means and standard deviations in parentheses for vegetation variables across ecosites at Possum Kingdom State Park in Texas. Given low samples sizes for some groups, we statistically compared means between the Clay Loam and Redland ecosites, and we provide the degrees of freedom (*df*), test statistics (*t*), and *P*-values (*P*) for each t-test below. Letters indicate significantly different means at $\alpha = 0.05$.

Scale	Vegetation Variables with >30 Observations	Clay Loam	Low Stony Hill	Redland	Sandstone Hill	Sandy Loam	*df*	*t*	*P*
Site[1]	Canopy cover	10.1 (23.6)	0.7 (1.9)	9.0 (16.4)	6.7 (10.7)	1.3 (1.2)	306.5	6.3	<0.01
	Shrub cover	14.4 (16.1)	6.5 (5.9)	14.0 (14.3)	23.3 (12.1)	8.3 (3.8)	265.4	0.3	0.78
	Herbaceous cover	32.5 (24.6)	57.5 (25.0)	53.9 (26.5)	46.3 (27.1)	70.0 (9.0)	227.6	-7.1	<0.01
	Bare cover	57.6 (28.3)	37.6 (27.2)	37.3 (25.1)	37.1 (29.4)	27.5 (12.5)	266.9	6.7	<0.01
	Ashe juniper canopy cover	18.1 (21.1)	0.0 (0.0)	6.3 (14.4)	2.0 (4.9)	0.0 (0.0)	308.7	5.9	<0.01

[1] Clay Loam *n* = 202, Low Stony Hill *n* = 18, Redland *n* = 117, Sandstone Hill *n* = 6, Sandy Loam = 3

Table D8. Means and standard deviations in parentheses for vegetation variables across ecosites at Balcones Canyonlands National Wildlife Refuge and adjacent private lands in Texas. We provide the associated Analysis of Variance results for site- and territory-scale metrics across ecosites with >30 observations in Table D4. Given small samples sizes for most nest-scale ecosites, we did not compare means statistically across groups.

Scale	Vegetation Variables with >30 Observations	Adobe	Blackland	Clay Loam	Low Stony Hill	Redland	Shallow	Steep Rocky
Site[1]	Canopy cover	32.1 (25.4)	0.0 (0.0)	9.4 (17.9)	18.3 (21.4)	11.1 (21.6)	21.7 (20.0)	31.2 (22.0)
	Shrub cover	12.0 (14.0)	2.5 (3.5)	18.8 (23.7)	24.5 (21.1)	10.5 (12.0)	13.7 (23.2)	16.9 (19.1)
	Herbaceous cover	22.3 (26.1)	100.0 (0.0)	62.2 (33.7)	39.3 (32.2)	81.3 (16.1)	58.1 (34.1)	14.2 (23.7)
	Bare cover	69.8 (27.6)	0.0 (0.0)	23.8 (24.8)	43.6 (30.9)	10.3 (8.0)	32.5 (29.9)	75.4 (29.1)
	Visual obstruction (0–1 m)	3.1 (5.9)	0.0 (0.0)	7.7 (21.0)	7.2 (11.6)	2.0 (5.0)	7.3 (13.5)	3.9 (5.5)
	Visual obstruction (1–2 m)	3.2 (5.3)	0.0 (0.0)	3.0 (8.2)	3.4 (5.9)	1.6 (5.0)	4.2 (5.4)	3.8 (4.7)
	Visual obstruction (2–3 m)	3.6 (5.5)	0.0 (0.0)	2.2 (5.3)	2.9 (5.7)	0.4 (1.1)	3.6 (6.3)	5.3 (6.9)
	Ashe juniper shrub cover	2.6 (4.7)	0.0 (0.0)	1.9 (5.8)	1.9 (5.0)	0.4 (1.5)	1.0 (1.9)	1.5 (5.2)
	Shin oak shrub cover	1.9 (5.1)	0.0 (0.0)	1.6 (6.6)	8.4 (13.9)	1.3 (5.0)	5.2 (16.1)	1.0 (2.6)
	Ashe juniper canopy cover	18.1 (17.4)	0.0 (0.0)	2.3 (5.7)	9.8 (15.5)	1.0 (4.0)	13.0 (14.9)	20.5 (17.6)
Territory[2]	Canopy cover	35.6 (23.9)	—	20.0 (25.5)	19.2 (21.6)	2.0 (4.0)	4.0 (11.6)	37.4 (22.4)
	Shrub cover	21.5 (20.8)	—	23.8 (8.8)	32.8 (23.9)	20.6 (14.2)	37.3 (24.2)	15.4 (15.8)
	Herbaceous cover	13.0 (21.0)	—	17.5 (24.7)	33.9 (29.6)	74.4 (18.2)	52.1 (26.3)	6.2 (15.9)
	Bare cover	67.1 (32.0)	—	71.3 (23.0)	43.1 (32.0)	5.0 (7.1)	23.9 (23.7)	88.3 (19.6)
	Visual obstruction (0–1 m)	4.3 (7.5)	—	1.0 (1.4)	11.4 (15.4)	2.5 (5.0)	16.9 (15.0)	2.4 (4.7)
	Visual obstruction (1–2 m)	3.5 (4.9)	—	0.0 (0.0)	6.1 (9.2)	0.0 (0.0)	2.7 (4.0)	2.4 (5.4)
	Visual obstruction (2–3 m)	3.5 (4.9)	—	2.0 (0.0)	3.2 (5.6)	0.0 (0.0)	1.0 (2.6)	3.1 (5.0)
	Agarita shrub cover	0.2 (1.0)	—	0.0 (0.0)	0.1 (0.4)	0.0 (0.0)	0.0 (0.0)	0.1 (0.6)
	Ashe juniper shrub cover	3.0 (5.9)	—	16.0 (2.8)	2.0 (4.9)	1.5 (1.9)	0.4 (1.6)	1.8 (2.7)
	Cedar elm shrub cover	0.1 (0.7)	—	0.0 (0.0)	0.3 (1.9)	1.5 (3.0)	0.0 (0.0)	0.0 (0.0)
	Elbowbush shrub cover	0.6 (2.0)	—	0.0 (0.0)	1.3 (4.3)	4.5 (5.3)	0.3 (1.1)	1.1 (3.3)
	Live oak shrub cover	0.3 (2.5)	—	0.0 (0.0)	1.3 (5.3)	1.0 (2.0)	5.1 (14.5)	0.0 (0.3)
	Shin oak shrub cover	5.2 (11.5)	—	0.0 (0.0)	12.5 (16.8)	4.0 (5.7)	19.4 (18.8)	3.0 (5.8)
	Texas ash shrub cover	0.2 (1.3)	—	0.0 (0.0)	0.3 (2.2)	0.0 (0.0)	0.0 (0.0)	1.4 (5.8)
	Texas oak shrub cover	1.2 (2.9)	—	3.0 (4.2)	0.6 (2.5)	1.0 (2.0)	0.0 (0.0)	0.5 (1.9)
	Texas persimmon shrub cover	1.0 (3.1)	—	0.0 (0.0)	0.4 (1.7)	0.5 (1.0)	0.0 (0.0)	0.2 (0.9)

	Ashe juniper canopy cover	16.8 (17.9)	—	11.0 (12.7)	9.7 (15.2)	0.0 (0.0)	1.9 (4.7)	20.1 (16.0)
	Flameleaf sumac canopy cover	0.3 (1.5)	—	0.0 (0.0)	0.23 (1.8)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)
	Live oak canopy cover	1.5 (6.3)	—	0.0 (0.0)	2.7 (8.7)	2.0 (4.0)	2.1 (8.0)	0.7 (2.7)
	Shin oak canopy cover	1.7 (6.4)		1.0 (1.4)	2.7 (7.5)	0.0 (0.0)	0.0 (0.0)	1.6 (5.0)
	Texas oak canopy cover	10.1 (14.8)		7.0 (9.9)	2.2 (7.2)	0.0 (0.0)	0.0 (0.0)	10.5 (14.7)
Nest[3]	Canopy cover	27.9 (24.7)	—	—	25.1 (22.4)	—	66.0 (NA)	—
	Shrub cover	32.0 (27.2)	—	—	46.6 (24.1)	—	2.5 (NA)	—
	Herbaceous cover	26.3 (29.0)	—	—	20.7 (22.4)	—	26.3 (NA)	—
	Bare cover	23.0 (32.0)	—	—	30.9 (32.7)	—	87.5 (NA)	—
	Visual obstruction (0–1 m)	11.1 (11.9)	—	—	15.6 (14.3)	—	10.0 (NA)	—
	Visual obstruction (1–2 m)	9.9 (10.4)	—	—	9.1 (11.0)	—	6.0 (NA)	—
	Visual obstruction (2–3 m)	6.0 (5.5)	—	—	4.4 (6.0)	—	18.0 (NA)	—
	Ashe juniper shrub cover	0.5 (1.2)	—	—	1.7 (4.2)	—	0.0 (NA)	—
	Elbowbush shrub cover	0.0 (0.0)	—	—	2.5 (7.6)	—	0.0 (NA)	—
	Flameleaf sumac shrub cover	2.4 (4.9)	—	—	3.4 (7.2)	—	0.0 (NA)	—
	Live oak shrub cover	0.8 (3.0)	—	—	2.2 (6.7)	—	2.0 (NA)	—
	Shin oak shrub cover	16.5 (21.1)	—	—	19.0 (19.7)	—	0.0 (NA)	—
	Texas oak shrub cover	0.1 (0.5)	—	—	0.5 (2.1)	—	0.0 (NA)	—
	Texas persimmon shrub cover	0.6 (1.4)	—	—	0.7 (2.4)	—	0.0 (NA)	—
	Ashe juniper canopy cover	5.1 (8.6)	—	—	6.1 (12.1)	—	64.0 (NA)	—
	Flameleaf sumac canopy cover	1.0 (4.0)	—	—	1.3 (4.7)	—	0.0 (NA)	—
	Live oak canopy cover	0.0 (0.0)	—	—	5.2 (13.2)	—	2.0 (NA)	—
	Shin oak canopy cover	1.6 (4.3)	—	—	5.7 (10.1)	—	0.0 (NA)	—
	Texas oak canopy cover	6.6 (12.6)	—	—	1.2 (5.9)	—	0.0 (NA)	—

[1] Adobe *n* =143, Blackland *n* = 2, Clay Loam *n* =18, Low Stony Hill *n* = 607, Redland *n* = 16, Shallow *n* = 21, Steep Rocky *n* = 67

[2] Adobe *n* =221, Clay Loam *n* = 2, Low Stony Hill *n* = 1,295, Redland *n* = 4, Shallow *n* = 14, Steep Rocky *n* = 91; Includes both golden-cheeked warbler (*Setophaga chrysoparia*) and black-capped vireo (*Vireo atricapilla*) territories

[3] Adobe *n* = 16, Low Stony Hill *n* = 356, Shallow *n* = 1; Includes only black-capped vireo nests

Table D9. Results from Analyses of Variance comparing mean site-scale and territory-scale vegetation metrics across ecosites ($n > 30$) at Balcones Canyonlands National Wildlife Refuge and adjacent private lands in Texas. We did not statistically compare mean nest-scale vegetation metrics across ecosites due to low sample sizes in the Adobe ($n = 16$ nests) and Steep Rocky ($n = 0$ nests) ecosites. We provide test statistics (F) and P-values (P) for each Analysis of Variance below. Letters indicate significantly different means at $\alpha = 0.05$.

Scale	Vegetation Variables with >30 Observations	Adobe	Low Stony Hill	Steep Rocky	F	P
Site[1]	Canopy cover	32.1 (25.4)^{A}	18.3 (21.4)^{B}	31.2 (22.0)^{A}	28.7	<0.01
	Shrub cover	12.0 (14.0)^{A}	24.5 (21.1)^{B}	16.9 (19.1)^{A}	25.1	<0.01
	Herbaceous cover	22.3 (26.1)^{A}	39.3 (32.2)^{B}	14.2 (23.7)^{C}	33.6	<0.01
	Bare cover	69.8 (27.6)^{A}	43.6 (30.9)^{B}	75.4 (29.1)^{A}	67.9	<0.01
	Visual obstruction (0–1 m)	3.1 (5.90)^{A}	7.2 (11.6)^{B}	3.9 (5.5)^{A}	10.4	<0.01
	Visual obstruction (1–2 m)	3.2 (5.3)	3.4 (5.9)	3.8 (4.7)	0.2	0.78
	Visual obstruction (2–3 m)	3.6 (5.5)^{AB}	2.9 (5.7)^{A}	5.3 (6.9)^{B}	5.6	<0.01
	Ashe juniper shrub cover	2.6 (4.7)	1.9 (5.0)	1.5 (5.2)	1.3	0.30
	Shin oak shrub cover	1.9 (5.12)^{A}	8.4 (13.9)^{B}	1.0 (2.6)^{A}	24.6	<0.01
	Ashe juniper canopy cover	18.1 (17.4)^{A}	9.8 (15.5)^{B}	20.5 (17.6)^{A}	25.7	<0.01
Territory[2]	Canopy cover	35.6 (23.9)^{A}	19.2 (21.6)^{B}	37.4 (22.4)^{A}	74.6	<0.01
	Shrub cover	21.5 (20.8)^{A}	32.8 (23.9)^{B}	15.4 (15.8)^{A}	42.2	<0.01
	Herbaceous cover	13.0 (21.0)^{A}	33.9 (29.6)^{B}	6.2 (15.9)^{A}	86.1	<0.01
	Bare cover	67.1 (32.0)^{A}	43.1 (32.0)^{B}	88.3 (19.6)^{C}	149.7	<0.01
	Visual obstruction (0–1 m)	4.3 (7.5)^{A}	11.4 (15.4)^{B}	2.4 (4.7)^{A}	37.3	<0.01
	Visual obstruction (1–2 m)	3.4 (4.9)^{A}	6.1 (9.2)^{B}	2.4 (5.4)^{A}	15.0	<0.01
	Visual obstruction (2–3 m)	3.5 (4.9)	3.2 (5.6)	3.1 (5.0)	0.3	0.71
	Agarita shrub cover	0.2 (1.1)^{A}	0.1 (0.4)^{B}	0.1 (0.6)^{AB}	3.8	0.02
	Ashe juniper shrub cover	3.0 (5.9)^{A}	2.0 (4.9)^{B}	1.8 (2.7)^{B}	1.2	0.02
	Cedar elm shrub cover	0.1 (0.8)	0.3 (1.9)	0.0 (0.0)	1.9	0.12
	Elbowbush shrub cover	0.6 (2.0)	1.3 (4.3)	1.1 (3.3)	2.8	0.06
	Live oak shrub cover	0.3 (2.5)^{A}	1.3 (5.3)^{B}	0.0 (0.0)^{A}	6.4	<0.01
	Shin oak shrub cover	5.2 (11.5)^{A}	12.5 (16.8)^{B}	3.0 (5.8)^{A}	33.3	<0.01

Texas ash shrub cover	0.2 (1.3)^{A}	0.3 (2.2)^{A}	1.4 (5.8)^{B}	9.4	<0.01
Texas oak shrub cover	1.2 (2.9)^{A}	0.6 (2.5)^{B}	0.5 (1.9)^{B}	5.2	<0.01
Texas persimmon shrub cover	1.0 (3.1)^{A}	0.4 (1.7)^{B}	0.2 (0.9)^{B}	10.1	<0.01
Ashe juniper canopy cover	16.8 (17.9)^{A}	9.7 (15.2)^{B}	20.1 (16.0)^{A}	34.7	<0.01
Flameleaf sumac canopy cover	0.3 (1.5)	0.23 (1.8)	0.0 (0.0)	0.9	0.41
Live oak canopy cover	1.5 (6.3)^{A}	2.7 (8.7)^{B}	0.7 (2.7)^{A}	4.1	0.02
Shin oak canopy cover	1.7 (6.4)	2.7 (7.5)	1.6 (5.0)	2.5	0.08
Texas oak canopy cover	10.1 (14.8)^{A}	2.2 (7.2)^{B}	10.5 (14.7)^{C}	95.3	<0.01

[1] Adobe *n* =143, Low Stony Hill *n* = 607, Steep Rocky *n* = 67; *df* = 2, 814 for all site-scale Analyses of Variance

[2] Adobe *n* =221, Low Stony Hill *n* = 1295, Steep Rocky *n* = 91; *df* = 2, 1604; Includes both golden-cheeked warbler (*Setophaga chrysoparia*) and black-capped vireo (*Vireo atricapilla*) territories

Table D10. Means and standard deviations in parentheses for vegetation variables across ecosites at Kerr Wildlife Management Area in Texas. We provide test statistics (*F*) and *P*-values (*P*) for each Analysis of Variance below. Letters indicate significantly different means at α = 0.05.

Scale	Vegetation Variables with >30 Observations	Clay Loam	Low Stony Hill	Redland	Steep Rocky	*F*	*P*
Site[1]	Canopy cover	20.6 (20.1)^{A}	21.4 (20.3)^{A}	16.7 (19.1)^{A}	29.4 (20.8)^{B}	7.5	<0.01
	Shrub cover	19.2 (11.9)^{AB}	21.5 (13.0)^{AB}	25.8 (15.2)^{A}	18.5 (12.9)^{B}	4.7	<0.01
	Herbaceous cover	43.7 (20.0)^{A}	37.7 (16.7)^{A}	40.1 (17.1)^{A}	27.4 (17.1)^{B}	18.0	<0.01
	Bare cover	38.8 (18.0)^{A}	41.9 (18.2)^{A}	35.1 (16.6)^{A}	54.9 (21.0)^{B}	22.5	<0.01
	Visual obstruction (0–1 m)	3.2 (3.6)	6.0 (9.0)	6.2 (8.8)	5.8 (9.2)	1.1	0.37
	Visual obstruction (1–2 m)	3.8 (4.9)^{A}	4.2 (5.4)^{A}	2.1 (3.1)^{A}	6.3 (8.7)^{B}	6.2	<0.01
	Visual obstruction (2–3 m)	3.5 (5.2)^{A}	3.8 (5.9)^{A}	3.9 (6.9)^{AB}	5.8 (8.0)^{B}	3.4	0.02
	Ashe juniper shrub cover	2.9 (4.0)^{AB}	2.5 (3.9)^{A}	1.5 (4.1)^{A}	3.7 (4.6)^{B}	4.1	<0.01
	Live oak shrub cover	3.2 (6.9)^{AB}	6.1 (8.8)^{A}	15.3 (15.1)^{C}	2.9 (6.4)^{B}	25.1	<0.01
	Ashe juniper canopy cover	11.9 (18.1)^{A}	9.3 (17.0)^{A}	4.0 (10.5)^{A}	20.4 (18.9)^{B}	18.1	<0.01
	Live oak canopy cover	6.5 (11.1)^{AB}	9.6 (13.2)^{A}	11.1 (14.2)^{A}	3.8 (7.7)^{B}	10.6	<0.01
Territory[2]	Canopy cover	—	18.0 (18.7)^{A}	12.4 (15.6)^{B}	30.9 (21.1)^{C}	64.7	<0.01
	Shrub cover	—	27.3 (17.5)^{AB}	29.5 (18.4)^{A}	24.5 (16.7)^{B}	5.1	<0.01
	Herbaceous cover	—	33.8 (18.8)^{A}	41.1 (17.0)^{B}	23.7 (16.0)^{C}	64.0	<0.01
	Bare cover	—	42.0 (20.8)^{A}	31.4 (15.5)^{B}	54.8 (22.2)^{C}	81.6	<0.01
	Visual obstruction (0–1 m)	—	7.4 (11.1)^{AB}	5.6 (8.7)^{A}	8.3 (12.1)^{B}	3.4	0.04
	Visual obstruction (1–2 m)	—	4.9 (8.4)^{A}	2.5 (4.3)^{B}	6.2 (9.4)^{A}	11.8	<0.01
	Visual obstruction (2–3 m)	—	3.9 (6.7)^{AB}	2.8 (5.2)^{A}	4.4 (5.9)^{B}	3.8	0.02
	Agarita shrub cover	—	0.2 (0.9)	0.3 (1.2)	0.1 (0.6)	2.8	0.06
	Ashe juniper shrub cover	—	1.6 (3.2)^{A}	1.3 (2.5)^{A}	3.2 (4.5)^{B}	23.1	<0.01
	Flameleaf sumac shrub cover	—	0.8 (2.8)^{A}	1.2 (3.4)^{A}	0.0 (0.2)^{B}	16.0	<0.01
	Hackberry shrub cover	—	0.2 (0.8)	0.3 (1.0)	0.3 (1.1)	0.5	0.62
	Eastern red bud shrub cover	—	0.5 (1.4)	0.2 (1.1)	0.5 (1.5)	1.8	0.17
	Live oak shrub cover	—	7.6 (10.5)^{A}	15.2 (14.6)^{B}	1.4 (3.9)^{C}	118.5	<0.01
	Texas persimmon shrub cover		0.4 (1.6)	0.2 (0.9)	0.5 (1.5)	2.2	0.12

	Ashe juniper canopy cover		8.2 (16.3)^{A}	0.9 (4.2)^{B}	19.6 (19.8)^{C}	87.1	<0.01
	Live oak canopy cover		7.2 (10.7)^{A}	10.7 (14.4)^{B}	2.6 (5.8)^{C}	39.4	<0.01
	Shin oak canopy cover		1.6 (5.5)	0.0 (0.0)	5.6 (10.8)	38.2	<0.01
Nest[3]	Canopy cover	—	23.3 (16.2)^{AB}	27.5 (18.1)^{A}	16.2 (13.8)^{B}	5.3	<0.01
	Shrub cover	—	43.8 (18.9)^{A}	46.7 (17.5)^{AB}	53.9 (17.9)^{B}	3.8	0.02
	Herbaceous cover	—	27.6 (19.0)	28.6 (14.0)	23.6 (14.9)	1.0	0.36
	Bare cover	—	30.5 (18.7)^{A}	25.4 (15.6)^{AB}	22.5 (12.6)^{B}	3.4	0.04
	Visual obstruction (0–1 m)	—	11.1 (12.2)	10.1 (9.2)	15.5 (14.5)	2.5	0.08
	Visual obstruction (1–2 m)	—	7.7 (7.4)^{AB}	5.8 (5.6)^{A}	10.1 (7.3)^{B}	4.5	0.01
	Visual obstruction (2–3 m)	—	5.2 (5.9)	6.5 (6.9)	8.6 (10.9)	2.5	0.08
	Ashe juniper shrub cover	—	0.9 (2.2)	1.7 (3.8)	0.6 (1.2)	2.5	0.08
	Flameleaf sumac shrub cover	—	2.0 (5.3)	2.4 (5.1)	0.1 (0.7)	2.8	0.07
	Live oak shrub cover	—	13.5 (15.3)^{A}	26.6 (16.8)^{B}	4.0 (9.5)^{C}	27.7	<0.01
	Eastern redbud shrub cover	—	1.4 (2.8)	1.1 (2.5)	0.7 (2.5)	0.7	0.5
	Shin oak shrub cover	—	10.0 (16.3)^{A}	0.9 (5.0)^{B}	30.1 (15.3)^{C}	53.4	<0.01
	Live oak canopy cover	—	13.3 (16.3)^{A}	22.5 (17.0)^{B}	1.1 (2.8)^{C}	22.8	<0.01
	Shin oak canopy cover	—	3.5 (8.8)^{A}	0.2 (1.5)^{A}	12.1 (13.9)^{B}	21.6	<0.01

[1] Clay Loam *n* =34, Low Stony Hill *n* = 210, Redland *n* = 42, Steep Rocky *n* = 187; *df* = 3, 469
[2] Clay Loam *n* = 6, Low Stony Hill *n* = 311, Redland *n* = 182, Steep Rocky *n* = 324; *df* = 2, 814; Includes golden-cheeked warbler (*Setophaga chrysoparia*) and black-capped vireo (*Vireo atricapilla*) territories
[3] Clay Loam *n* = 1, Low Stony Hill *n* = 84, Redland *n* = 61, Steep Rocky *n* = 35; *df* = 3,177; Includes only black-capped vireo nests

APPENDIX E: Comparisons of Vegetation Between Successful and Unsuccessful Territories

Table E3. Mean percentages and standard deviations in parentheses of general vegetation variables for successful (i.e., fledged $\geq$1 host young) and unsuccessful (i.e, male paired but did not fledge host young) golden-cheeked warbler (*Setophaga chrysoparia*) territories at Possum Kingdom State Park in Texas (Possum Kingdom), Balcones Canyonlands National Wildlife Refuge and nearby private lands in Texas (Balcones), and Kerr Wildlife Management Area in Texas (Kerr).

Study Area[1]	Variable[2]	Successful[1]	Unsuccessful[1]
Possum Kingdom	Bare ground	69.1 (6.6)	48.2 (10.6)
	Canopy cover	46.7 (9.4)	37.2 (19.1)
	Shrub cover	14.2 (4.4)	8.0 (2.2)
	Herbaceous cover	25.0 (10.0)	43.3 (17.1)
	Visual obstruction (0–1 m)	0.0 (0.0)	1.6 (0.4)
	Visual obstruction (1–2 m)	0.0 (0.0)	0.7 (0.5)
	Visual obstruction (2–3 m)	0.0 (0.0)	0.0 (0.0)
Balcones	Bare ground	77.5 (15.5)	80.8 (19.0)
	Canopy cover	40.5 (12.3)	39.69 (14.8)
	Shrub cover	25.8 (16.2)	19.5 (13.6)
	Herbaceous cover	7.1 (8.9)	9.2 (12.4)
	Visual obstruction (0–1 m)	6.2 (8.5)	3.4 (3.2)
	Visual obstruction (1–2 m)	4.8 (5.1)	2.9 (2.6)
	Visual obstruction (2–3 m)	4.6 (3.9)	3.5 (3.0)
Kerr	Bare ground	68.6 (11.6)	66.7 (11.8)
	Canopy cover	13.2 (10.5)	41.9 (16.5)
	Shrub cover	15.6 (7.5)	16.2 (9.1)
	Herbaceous cover	16.5 (8.9)	18.3 (10.6)
	Visual obstruction (0–1 m)	4.7 (4.5)	3.2 (3.4)
	Visual obstruction (1–2 m)	4.7 (4.5)	3.9 (2.3)
	Visual obstruction (2–3 m)	4.7 (3.7)	4.6 (3.3)

[1] Possum Kingdom: 5 of 10 warbler males paired and 2 warbler males that paired fledged young; Balcones: 104 of 114 warbler males paired and 66 of warbler males that paired fledged young; Kerr: 46 of 46 warbler males paired and 33 of warbler males that paired fledged young

[2] Mean percentages

Table E4. Mean percentages and standard deviations in parentheses of general vegetation variables for successful (i.e., fledged ≥1 host young) and unsuccessful (i.e, male paired but did not fledge host young) black-capped vireo (*Vireo atricapilla*) territories the Wichita Mountains Wildlife Refuge and adjacent Fort Sill Military Reservation in Oklahoma (Wichita Mountains), Balcones Canyonlands National Wildlife Refuge and nearby private lands in Texas (Balcones), and Kerr Wildlife Management Area in Texas (Kerr).

Study Area[1]	**Variable[2]**	**Successful[1]**	**Unsuccessful[1]**
Wichita Mountains	Bare ground	31.7 (11.6)	35.1 (15.4)
	Canopy cover	19.3 (14.9)	20.1 (14.6)
	Shrub cover	28.8 ()11.2	23.8 (12.3)
	Herbaceous cover	47.5 (18.8)	45.7 (12.8)
	Visual obstruction (0–1 m)	8.3 (6.7)	6.8 (5.9)
	Visual obstruction (1–2 m)	4.8 (5.3)	3.9 (3.6)
	Visual obstruction (2–3 m)	3.8 (5.0)	3.0 (3.7)
Balcones	Bare ground	32.7 (19.4)	34.4 (20.9)
	Canopy cover	11.9 (10.8)	13.5 (12.2)
	Shrub cover	35.4 (18.8)	34.4 (17.7)
	Herbaceous cover	40.7 (19.2)	39.6 (20.6)
	Visual obstruction (0–1 m)	12.7 (11.2)	13.1 (12.8)
	Visual obstruction (1–2 m)	6.4 (7.0)	6.7 (7.0)
	Visual obstruction (2–3 m)	2.4 (3.6)	2.8 (3.4)
Kerr	Bare ground	35.4 (13.3)	37.1 (12.9)
	Canopy cover	15.0 (12.2)	13.0 (10.0)
	Shrub cover	30.9 (12.4)	31.4 (12.3)
	Herbaceous cover	37.1 (11.6)	35.0 (13.2)
	Visual obstruction (0–1 m)	9.4 (8.0)	8.9 (9.7)
	Visual obstruction (1–2 m)	5.5 (6.6)	5.2 (6.6)
	Visual obstruction (2–3 m)	4.1 (5.0)	3.0 (3.4)

[1] Wichita Mountains: 215 of 215 male vireos paired and 179 of males that paired fledged young; Balcones: 207 of 215 male vireos paired and 123 of male vireos that paired fledged young; Kerr: 163 of 164 male vireos paired and 101 of male vireos that paired fledged young

[2] Mean percentages

APPENDIX F: Comparisons of Vegetation Between Successful and Unsuccessful Nests

Table F3. Mean percentages and standard deviations in parentheses of general vegetation variables for successful (i.e., fledged $\geq$1 host young) and unsuccessful golden-cheeked warbler (*Setophaga chrysoparia*) nests at Possum Kingdom State Park in Texas (Possum Kingdom) and Kerr Wildlife Management Area in Texas (Kerr).

Study Area[1]	**Variable**[2]	**Successful**[1]	**Unsuccessful**[1]
Balcones	Bare ground	85.0 (21.4)	81.1 (11.4)
	Canopy cover	47.6 (17.1)	49.7 (13.5)
	Shrub cover	24.7 (18.6)	17.5 (17.6)
	Herbaceous cover	4.2 (5.8)	15.4 (13.0)
	Visual obstruction (0–1 m)	3.3 (6.1)	2.3 (4.5)
	Visual obstruction (1–2 m)	3.8 (5.0)	6.0 (5.4)
	Visual obstruction (2–3 m)	4.8 (6.4)	4.9 (3.8)
Kerr	Bare ground	78.5 (6.8)	92.5 (—)
	Canopy cover	47.2 (8.8)	62.0 (—)
	Shrub cover	11.0 (5.2)	2.5 (—)
	Herbaceous cover	10.5 (7.4)	5.0 (—)
	Visual obstruction (0–1 m)	2.0 (3.5)	0.0 (—)
	Visual obstruction (1–2 m)	2.0 (3.5)	0.0 (—)
	Visual obstruction (2–3 m)	5.6 (3.8)	6.0 (—)

[1] Balcones: n = 18 successful warbler nests and n = 7 unsuccessful warbler nests; Kerr: n = 5 successful warbler nests and n = 1 unsuccessful warbler nests.

Table F4. Mean percentages and standard deviations in parentheses of general vegetation variables for successful (i.e., fledged ≥1 host young) and unsuccessful black-capped vireo (*Vireo atricapilla*) nests at the Wichita Mountains Wildlife Refuge and adjacent Fort Sill Military Reservation in Oklahoma (Wichita Mountains), Balcones Canyonlands National Wildlife Refuge and nearby private lands in Texas (Balcones), and Kerr Wildlife Management Area in Texas (Kerr).

Study Area	**Variable**	**Successful**[1]	**Unsuccessful**[1]
Wichita Mountains	Bare ground	29.5 (20.8)	34.8 (22.0)
	Canopy cover	33.1 (20.4)	35.2 (20.9)
	Shrub cover	38.9 (21.4)	37.2 (18.3)
	Herbaceous cover	36.7 (19.5)	35.5 (18.9)
	Visual obstruction (0–1 m)	13.8 (12.7)	13.2 (13.6)
	Visual obstruction (1–2 m)	11.1 (9.4)	11.4 (9.9)
	Visual obstruction (2–3 m)	8.4 (9.5)	9.4 (9.3)
Balcones	Bare ground		
	Canopy cover	24.1 (23.8)	25.5 (21.7)
	Shrub cover	46.4 (24.6)	45.2 (24.6)
	Herbaceous cover	20.3 (21.5)	23.3 (24.6)
	Visual obstruction (0–1 m)	16.1 (14.1)	14.9 (14.6)
	Visual obstruction (1–2 m)	8.6 (12.2)	9.9 (2.2)
	Visual obstruction (2–3 m)	4.3 (6.0)	4.8 (6.1)
Kerr	Bare ground	26.1 (16.9)	27.8 (16.3)
	Canopy cover	24.1 (16.9)	23.3 (18.2)
	Shrub cover	46.2 (20.2)	47.4 (18.6)
	Herbaceous cover	29.8 (19.2)	25.5 (15.1)
	Visual obstruction (0–1 m)	11.4 (12.2)	12.1 (12.1)
	Visual obstruction (1–2 m)	7.4 (6.9)	7.5 (6.7)
	Visual obstruction (2–3 m)	5.2 (5.8)	6.2 (7.6)

[1] Wichita Mountains: n = 147 successful vireo nests and n = 110 unsuccessful vireo nests; Balcones: n = 129 successful vireo nests and n = 213 unsuccessful vireo nests; Kerr: n = 65 successful vireo nests and n = 100 unsuccessful vireo nests.

APPENDIX G: Model Results

Table G1. Results of best fit models for vegetation data collected at Wichita Mountains Wildlife Refuge and adjacent Fort Sill in Oklahoma. Model names with no superscript indicate that the linear model was the best fit for the vegetation variable and model names with a superscript "2" indicate that the quadratic model was the best fit for the vegetation variable. Also see Figures 17–20.

Scale[1]	Model	*F*	*P*	r^2
Site	Canopy cover	0.00	0.97	0.00
	Shrub cover[2]	8.48	0.00	0.06
	Herbaceous cover	2.43	0.12	0.00
	Bare cover[2]	6.75	0.00	0.04
	Blackjack oak shrub cover	27.03	<0.01	0.09
	Post oak canopy cover	0.46	0.50	0.00
Territory	Canopy cover[2]	1.51	0.22	0.00
	Shrub cover	58.63	<0.01	0.21
	Herbaceous cover	50.95	<0.01	0.19
	Bare cover	3.72	0.03	0.02
	Blackjack oak canopy cover	26.85	<0.01	0.11
	Blackjack oak shrub cover[2]	49.96	<0.01	0.31
Nest	Canopy cover[2]	4.13	0.02	0.02
	Shrub cover	38.34	<0.01	0.20
	Herbaceous cover	38.46	<0.01	0.11
	Bare cover[2]	6.70	0.00	0.04
	Blackjack oak canopy cover	9.50	0.00	0.03
	Blackjack oak shrub cover	113.5	<0.01	0.27

[1] *Df* site-scale linear models = 1, 263, *df* site-scale quadratic models = 2, 262, *df* territory-scale linear models = 1, 213, *df* territory-scale quadratic models = 2, 212, *df* nest-scale linear models = 1, 301, and *df* nest-scale quadratic models = 2, 300

Table G2. Results of best fit models for vegetation data collected at Possum Kingdom State Park in Texas. Model names with no superscript indicate that the linear model was the best fit for the vegetation variable and model names with a superscript “2” indicate that the quadratic model was the best fit for the vegetation variable. Also see Figure 21.

Scale[1]	Model	*F*	*P*	r^2
Site	Canopy cover	352.5	<0.01	0.53
	Shrub cover	24.94	<0.01	0.07
	Herbaceous cover[2]	34.14	<0.01	0.17
	Ashe juniper canopy cover	307.5	<0.01	0.49

[1] *Df* site-scale linear models = 1, 317 and *df* site-scale quadratic models = 2, 316

Table G3. Results of best fit models for vegetation data collected at Balcones Canyonlands National Wildlife Refuge and adjacent private properties. Model names with no superscript indicate that the linear model was the best fit for the vegetation variable and model names with a superscript "2" indicate that the quadratic model was the best fit for the vegetation variable.

Scale	Model	*F*	*P*	r^2
Site[1]	Canopy cover^2	59.12	<0.01	0.12
	Shrub cover	0.83	0.36	0.00
	Herbaceous cover^2	69.9	<0.01	0.14
	Ashe juniper canopy cover^2	45.16	<0.01	0.10
Warbler Territory	Canopy cover	0.50	0.83	0.00
	Shrub cover	0.40	0.53	0.00
	Herbaceous cover^2	3.88	0.02	0.05
	Ashe juniper canopy cover	0.01	0.92	0.00
Vireo Territory	Canopy cover^2	3.75	0.03	0.03
	Shrub cover	4.52	0.03	0.02
	Herbaceous cover^2	4.85	0.01	0.03
	Shin oak shrub cover	1.95	0.16	0.00
Vireo Nest	Canopy cover	3.61	0.58	0.00
	Shrub cover	4.46	0.04	0.00
	Herbaceous cover	0.95	0.33	0.00
	Ashe juniper canopy cover	4.56	0.03	0.00
	Shin oak shrub cover	4.09	0.02	0.02

[1] *Df* site-scale linear models = 1, 815; *df* site-scale quadratic models = 2, 814; *df* warbler territory-scale linear models = 1, 112; *df* warbler territory-scale quadratic models = 2, 111; *df* vireo territory-scale linear models = 1, 213; *df* vireo territory-scale quadratic model = 2, 212; *df* vireo nest-scale linear model = 1, 399; *df* vireo nest scale quadratic models = 2, 398

Table G4. Results of best fit models for vegetation data collected at Kerr Wildlife Management Area in Texas. Model names with no superscript indicate that the linear model was the best fit for the vegetation variable and model names with a superscript "2" indicate that the quadratic model was the best fit for the vegetation variable.

Scale	Model	F	P	r^2
Site	Canopy cover	5.08	0.02	0.01
	Shrub cover^2	8.02	0.00	0.03
	Herbaceous cover	1.35	0.25	0.00
	Bare cover^2	8.71	0.00	0.03
	Ashe juniper canopy cover	7.13	0.01	0.01
Warbler Territory	Canopy cover	0.03	0.87	0.00
	Shrub cover	3.67	0.06	0.06
	Herbaceous cover^2	5.67	0.01	0.17
	Bare cover^2	5.31	0.01	0.16
	Ashe juniper canopy cover	0.37	0.55	0.00
Vireo Territory	Canopy cover^2	3.55	0.03	0.03
	Shrub cover	18.46	<0.01	0.10
	Herbaceous cover^2	8.98	<0.01	0.09
	Bare cover^2	2.23	0.11	0.01
	Ashe juniper canopy cover	2.24	0.14	0.01
Vireo Nest	Canopy cover^2	19.60	<0.01	0.16
	Shrub cover	2.81	<0.01	0.05
	Herbaceous cover	10.25	<0.01	0.05
	Bare cover	0.34	0.56	0.00
	Ashe juniper canopy cover^2	10.57	<0.01	0.09
	Live oak canopy cover	112.8	<0.01	0.31
	Live oak shrub cover^2	27.26	<0.01	0.22
	Shin oak canopy cover^2	34.53	<0.01	0.26
	Shin oak shin cover^2	62.59	<0.01	0.39

[1] *Df* site-scale linear models = 1, 471; *df* site-scale quadratic models = 2, 470; *df* warbler territory-scale linear models = 1, 44; *df* warbler territory-scale quadratic models = 2, 43; *df* vireo territory-scale linear models = 1, 162; *df* vireo territory-scale quadratic model = 2, 261; *df* vireo nest-scale linear model = 1, 189; *df* vireo nest scale quadratic models = 2, 188